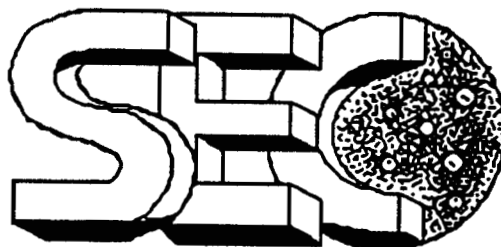


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Selene Engineering Company

(NASA-CR-184754) A LUNAR CONSTRUCTION SHACK
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Final Design
for
A Lunar Construction Shack Vehicle

Final Design
For
A Lunar Construction Shack Vehicle

Spacecraft Mission Design Class
The University of Texas at Austin
Department of Aerospace Engineering
under the direction of
Dr. Wallace T. Fowler

Spring 1988

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1.0 Introduction

A lunar construction shack vehicle is a critical component in most of the plans put forward for the construction of a permanent base on the moon. The Selene Engineering Company (SEC) has developed a concept for this vehicle which we feel is both innovative and practical. Our design makes use of the most advanced technology available to meet the design goals for a safe, versatile and durable habitat that will serve as a starting point for the initial phase of the construction of a permanent lunar base.

This document outlines SEC's proposed design for a lander vehicle which will be fully self-sufficient and will provide for all necessary life support, including consumables and radiation protection, needed by the construction crew until they can complete the assembly of a more permanent habitat. Since it is highly likely that it will take more than one crew to complete the construction of a permanent lunar base, our design has placed an emphasis on systems which can be easily maintained and resupplied and which will take a minimum of start up preparation by succeeding crews.

In order to minimize the mass transported to the lunar surface, none of the lander's components will be discarded. The design of components not needed for the the continuing operation of the habitat will include an alternate use as structural parts or tools.

With the assistance of the National Aeronautics and Space Administration (NASA) and the Universities Space Research Association (USRA) we feel we have developed a safe, reliable and versatile design for the lunar lander. SEC's lunar construction shack can function as a practical stepping stone toward a permanent lunar base.

1.1 Lander Design Requirements:

Vehicle must provide living quarters on the moon for a crew of eight for three weeks. The crew size was specified in the RFP and is considered to be a likely number of astronauts needed to construct a lunar base.

Vehicle must provide radiation shielding in the case of a solar flare. During a solar flare event large amounts of radiation are emitted from the sun and would be fatal in a short time to an unprotected crew on the moon.

Any vehicle portion which will not be returned to lunar orbit with the crew must be usable as an integral part of the Moonbase. This is to minimize the amount of mass transported to the moon and reduce the number of parts that must be discarded on the moon.

The vehicle must be able to be completely refitted with a resupply of consumables. The number of days required to complete the construction of a permanent lunar base is expected to exceed the allowable length of a single mission so the construction shack will be used as a base by two or more construction crews at different times.

1.2 Design Assumptions

Earthport is fully operational and capable of assembling the lander in orbit. The lander will be transported to the Earthport facility in sections by a HLLV or by the Shuttle and will be assembled there prior to its making its orbital transfer to the moon. The Earthport facility will be required to fuel the descent stage of the lander as well as the OTV and provide a place from which the OTV can launch.

A vehicle capable of transporting the lander and crew from Earth orbit to lunar orbit exists and is known to be reliable. This will probably be in the form of separate OTV's for the lander and crew. The lander OTV must have a power system capable of maintaining the cryogenic fuel storage and will probably need to top off the lander's fuel tanks just before the lander makes its descent to the lunar surface. The crew will proceed to the moon only after the shack has landed and been checked out.

The moonbase site has been selected and mapped. This must include a carefully selected landing site for the shack since the base will, by necessity, have to be constructed near the shack or possibly, outwards from where the shack lands.

All materials necessary for the construction of the Moonbase have been delivered to the site. No construction materials *per se* will be transported on the shack although some components of the shack will be reused in the construction of the Moonbase.

Technology Baseline will be assumed to be 2000. All technological advances necessary for the construction of the lunar base will be assumed to have been made, including all necessary construction equipment and techniques. Construction equipment is assumed to include lunar regolith diggers and a means of piling the regolith up on top of the shack.

A crew transportation vehicle capable of ferrying 8 crew members from lunar orbit to the Moonbase site and back again is available. This vehicle will be used to rotate the crews in and out of the shack and must be capable of carrying any supplies needed to refit the shack for the use by the new crew. A landing site relatively close to the shack is assumed and techniques for transporting supplies from the crew transportation vehicle to the Shack will have to be developed.

1.3 Management Update

Selene Engineering Company is divided into two integrated divisions; the Spacecraft Engineering Team and the Human Engineering Team. The Spacecraft Engineering Team is in charge of the design of all technical aspects of the spacecraft operation. The Human Engineering Team handles the life science aspects of the mission design. SEC consists of nine engineers (Figure 1.3-1): a Project Manager, two Team Leaders, an Operations Manager, and five Design Engineers. Figure 1.3-2 lists the presentations and reports given by SEC and those planned for the future.

1.4 Cost Update

SEC forecasted a workload of nine hours a week per engineer. This has not been a realistic estimate. SEC engineers have instead worked an average of 12 hours as indicted in Figure 1.4-1. Due to the extra work done by the design teams our original cost estimate was too low. The actual cost of the project and the expected cost are graphically represented in Figure 1.4-2.

The management structure which SEC developed has enhanced the efficiency of the individual engineers. The ease of communication and exchange of ideas between teams has allowed SEC to fulfill its design goals.

Organizational Chart

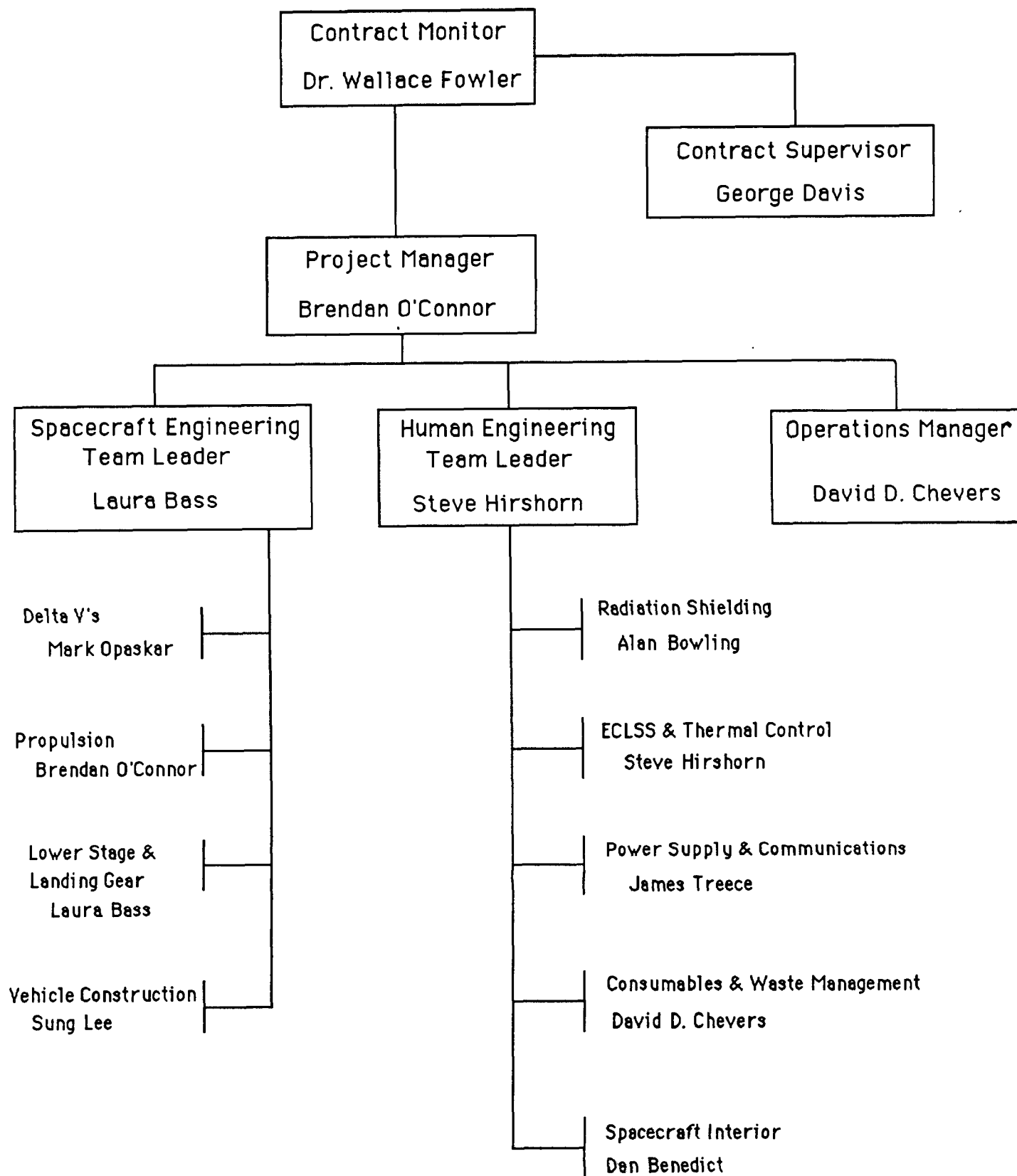


Figure 1.3-1

Project Milestone Chart

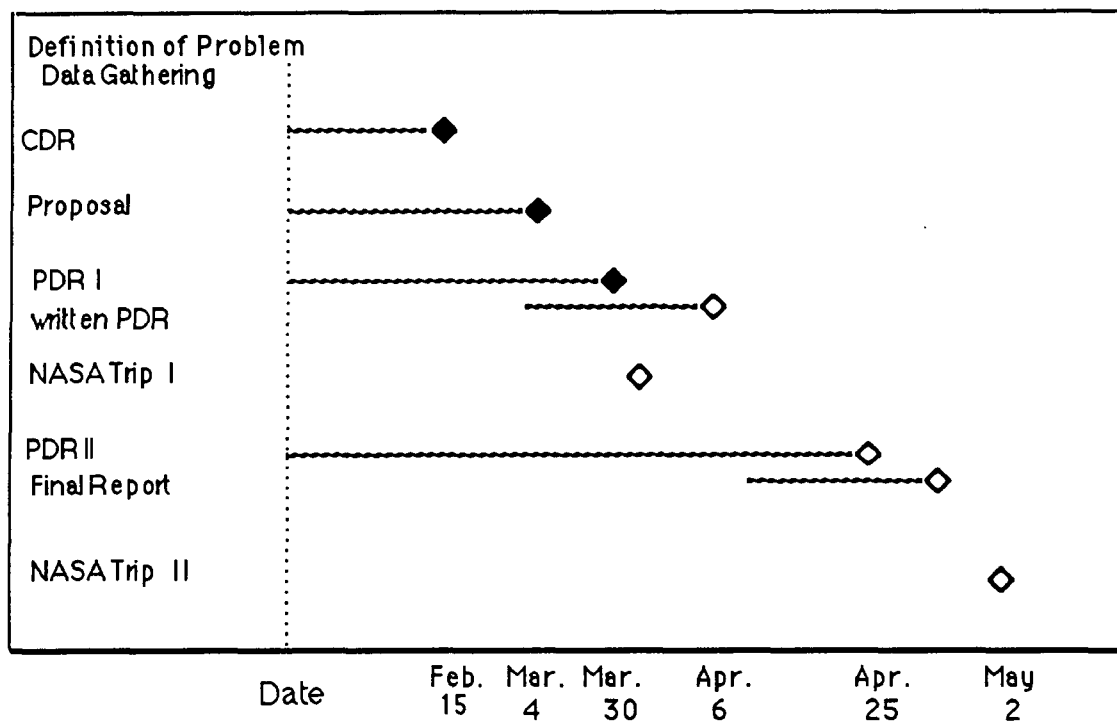


Figure 1.3-2

S.E.C. TOTAL MANHOURS TO DATE

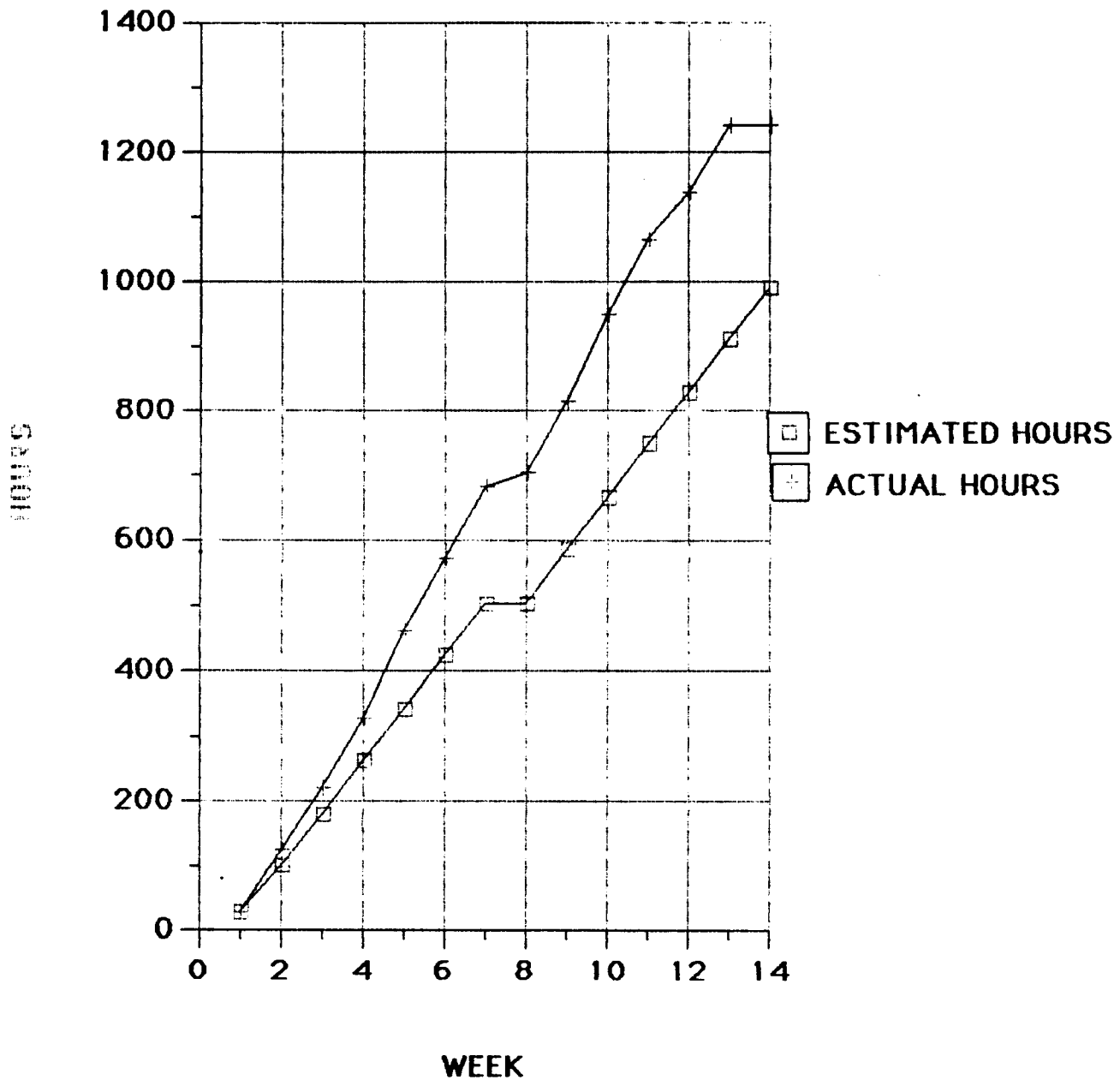


Figure 1.4-1

S.E.C. COST UPDATE

Table 1.4-1

MANPOWER COSTS

PROPOSAL MANPOWER ESTIMATE	\$23562
ACTUAL MANPOWER TO DATE	\$24796

MATERIAL COSTS

	PROPOSED	ACTUAL
3 RENTED COMPUTERS	\$2250	\$2250
MAINFRAME COMPUTER	\$100	\$30
PHOTOCOPIES	\$250	\$150
TRANSPARENCIES	\$50	\$100
PLASTIC MODEL PARTS	\$25	\$25
CONSULTANT FEES	\$800	\$400
+10%	\$428	
MATERIAL TOTAL	\$4703	\$2955
<u>TOTAL COSTS</u>	\$28265	\$27751

S.E.C. MANPOWER COSTS TO DATE

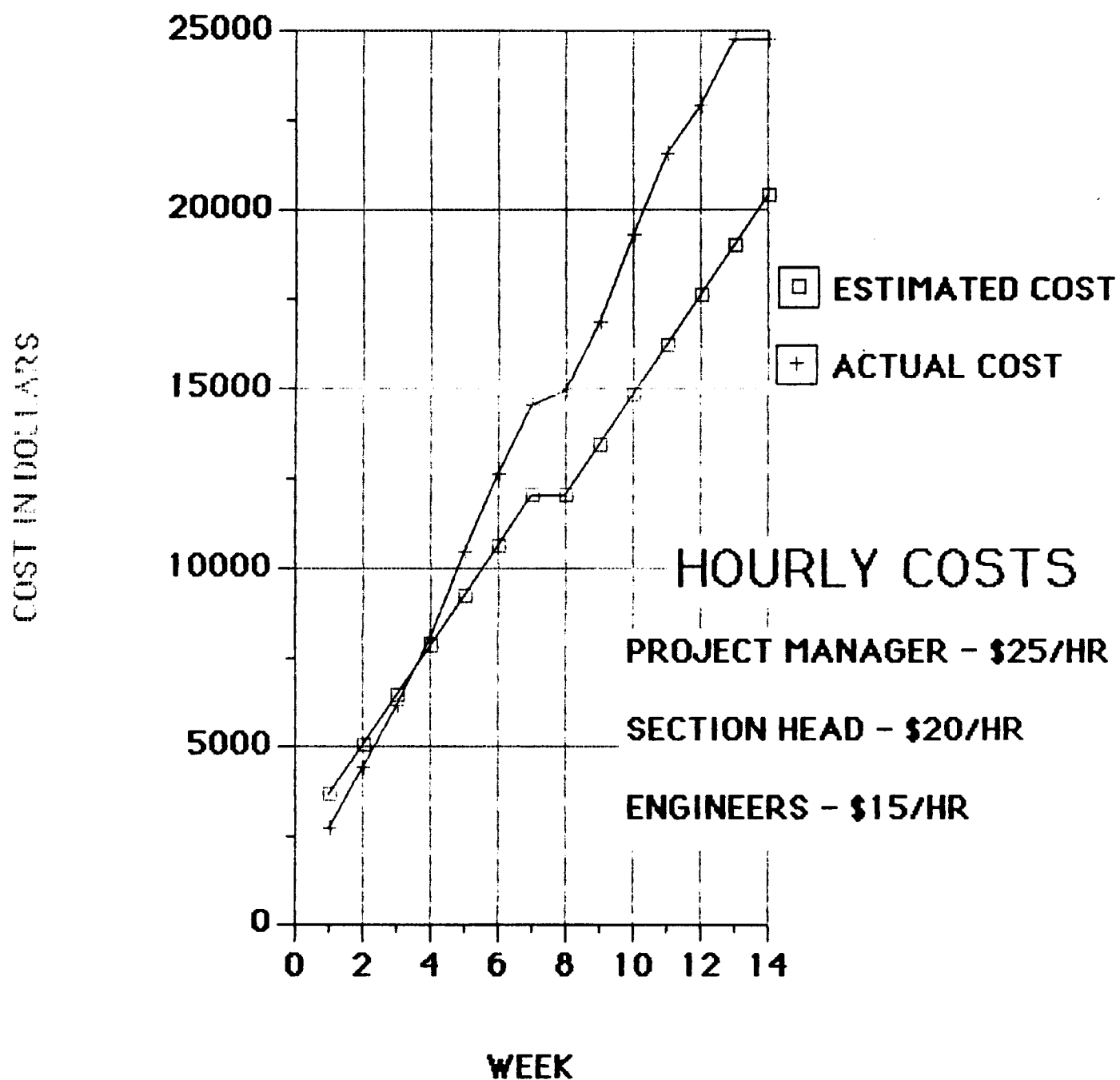


Figure 1.4-2

2.0 SPACECRAFT OVERVIEW

2.1 Overall mission scenario

The mission scenario for the lunar shack operation is based on the assumptions presented in the previous section. The mission scenario is consisted of eight stages :

1. Launch from the Earth to LEO.
2. Assembly in LEO
3. LEO to LLO
4. Landing of the lunar shack on the lunar surface
5. Landing of the crew
6. Ground preparations
7. Surface operations
8. Crew transportation to LLO

The shack and other parts such as a lower stage, airlocks, tanks etc. are launched by a heavy launch vehicle. The parts are assembled completely in LEO so that when the shack arrives on the lunar surface it is ready to operate.

The shack travels to LLO, and performs de-orbiting and landing by remote control. After landing of the shack, the crew of 8 lands on the surface separately in the crew vehicle approximately 1 week later. The 1 week interval between landing of the shack and the crew is assumed to find out if landing of the shack was successful and systems onboard the shack are operational.

Following landing of the crew, the engine is removed and the landing gear of the lower stage is lowered, so that the shack can be lowered to rest on the lower stage. Then, the landing is removed. The shack and the lower stage are supported by leveler mechanisms located under the lower stage to maintain levelness of the shack. The removed landing gear is disassembled and will be used in construction of the lunar base.

The shack is to be covered with lunar soil to protect the crew from solar flare radiation. The equipment under consideration for covering the shack is a digger which moves $260 \text{ m}^3/\text{hr}$ (Ref. Georgia Institute of Technology). However, a better and more reliable equipment is desired because the

digger does not seem to be a very reliable equipment for the job. It is assumed that a nuclear power reactor is in position prior to landing of the shack. The crew should set the reactor fully operational and do testing. The time needed for the set-up, testing and connecting power lines between the shack and the reactor is estimated to be no longer than 1 week. Therefore, the shack has to provide power for 1 week maximum. After the initial week, the nuclear power reactor will provide necessary power for the shack. The power supply of the shack will then be used as an emergency power supply in case of failure of the nuclear power reactor. The nuclear reactor will be left on the surface and provide power for the lunar base.

Surface operations are devoted to construction of initial lunar base. Upon the completion of the mission, the crew ascends in the crew transportation vehicle leaving its lower stage as shown in Figure 2.1-1. The lower stage, made of generic "tinker toy" parts will be disassembled and used for the lunar base construction. The shack can then be resupplied for use by later construction crews.

2.2 Habitation Module Construction Requirements

The requirements needed to ensure the safety of the habitation module were obtained from NASA documents. The module is basically a pressure cylinder which has to sustain an interior pressure of 12 psia. In addition to this pressure, the module has to support all the equipment which will be mounted inside the module. The module also has to withstand the stress incurred during lift-off from Earth and landing on the lunar surface.

For design configurations using space station common modules, a previous study done for NASA (Ref. JSC Memorandum 19989) suggests the use of all welded, integrally machined skin-stringer panels made of 2219-T851 aluminum plate. Several primary ring frames and intermediate ring frames within the module are proposed to stiffen the module and provide structures for equipment to be mounted inside the module.

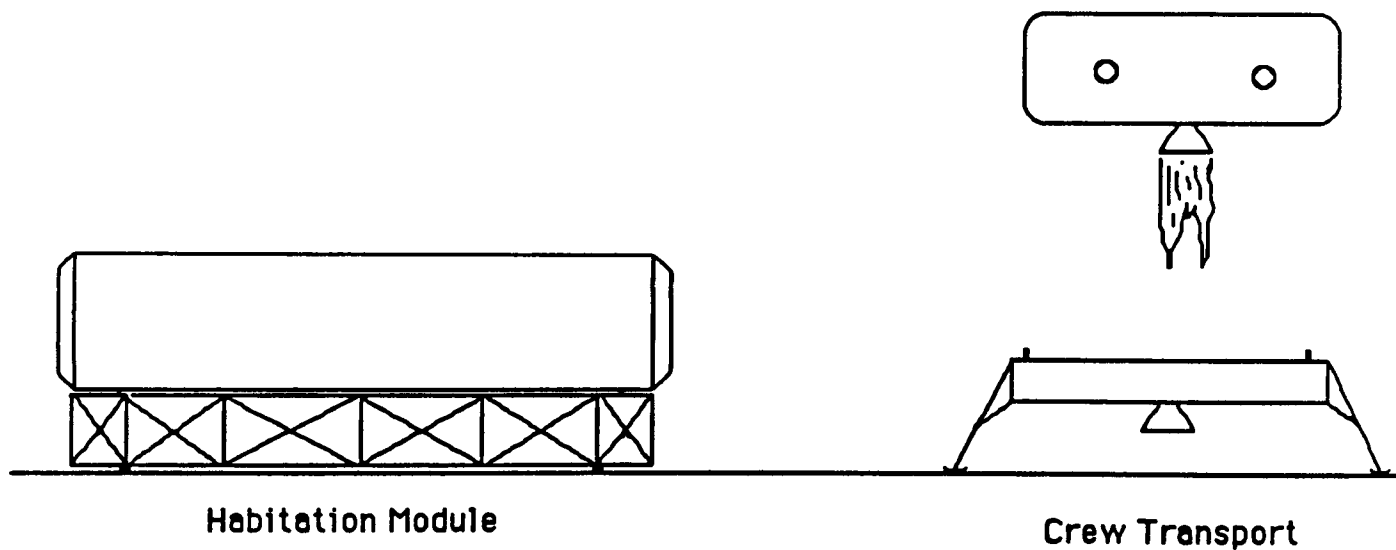
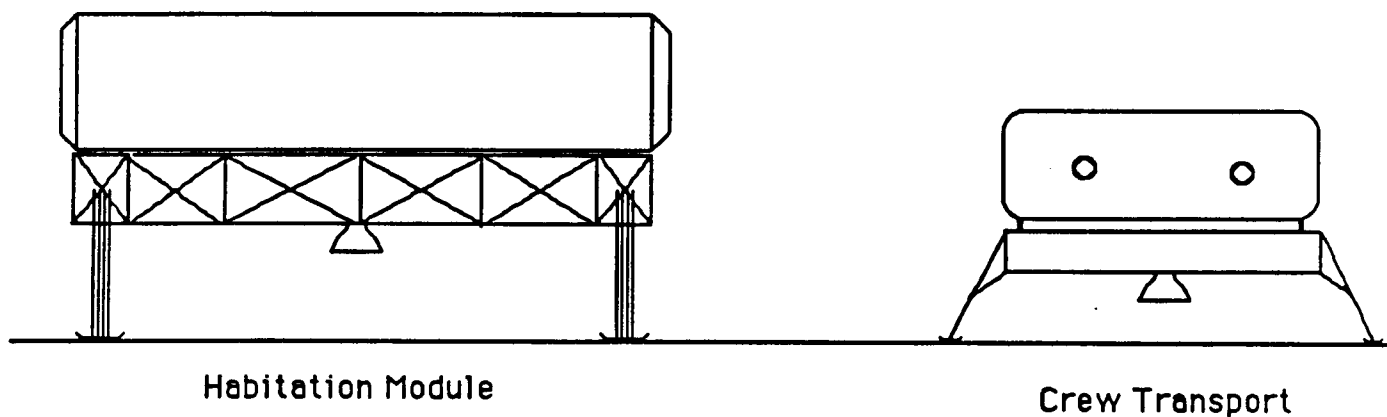
Table 2.2-1

MODULE CONSTRUCTION REQUIREMENTS

- 1. THE MODULE MATERIALS SHOULD PROVIDE A SERVICE LIFE OF 10 YEARS WITHOUT INTERMEDIATE REPAIR.**
- 2. MUST PROVIDE STRENGTH AND STRUCTURAL INTEGRITY SUFFICIENT TO SUSTAIN AN ENVIRONMENT OF 12 PSIA*.**
- 3. SHOULD PROVIDE INTERNAL ATTACHMENT STRUCTURES FOR MODULE EQUIPMENT AND EXTERNAL ATTACHMENTS FOR RESUPPLY.**
- 4. SHOULD PROVIDE METEOROID AND DEBRIS PROTECTION.**
- 5. SUBSYSTEMS SHOULD BE MODULARIZED SO THAT THEY CAN BE REPLACED WITH AVAILABLE SPARES IN CASE OF FAILURE.**
- 6. STRUCTURAL SAFETY FACTORS:**
 - FACTOR OF SAFETY OF AT LEAST 2.0 FOR PRESSURE LOADING**
 - FACTOR OF SAFETY OF 1.5 FOR MECHANICAL AND THERMAL LOADING.**

*** Justification for 12 psia will be given in a later section.**

Operation of the Lunar Lander



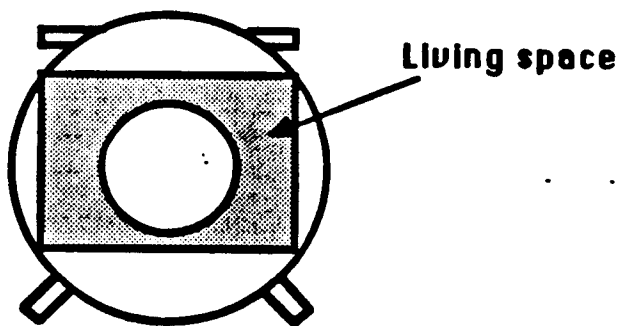
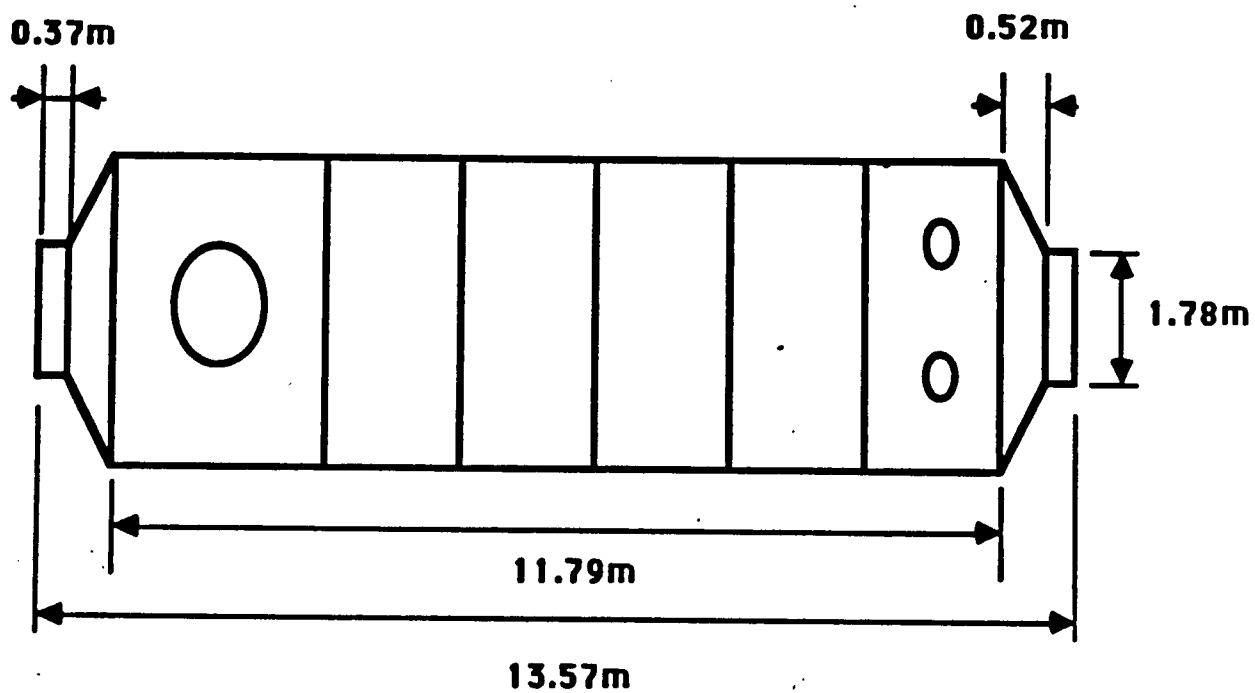
- Habitat and Crew Land Separately
- Habitat is lowered to the ground automatically
- Three Design Options for the Habitat Configuration

Figure 2.1-1

Since in SEC's design the module is to be covered with lunar regolith while on the lunar surface, there will not be a great need for micrometeorite and debris protection. The module still needs some protection, however, because it may be exposed during transition or it may eventually be used as an on-the-surface structure for the lunar base. A double-wall bumper which has a 0.11 cm thick aluminum bumper located 5 cm away from the module pressure skin is proposed. The 5 cm gap is filled with multilayer insulation to provide thermal control and may also improve the meteoroid and debris protection.

The proposed thickness of module skin is 0.18 cm. There is some question as to whether the 0.18 cm thick module skin is sufficient to resist the loading caused by meteoroid and debris impact with the limited 5 cm spacing between skins. The module is shown in Figure 2.2-1.

For the tin can design, the precise thickness of the wall and floor would have to be decided by stress analysis and tests. The construction requirements, however, remain the same as for the designs using space station common modules.



OVERALL MODULE GEOMETRY

Figure 2.2-1

2.3 Design Options

Four design configurations (Figures 2.3-1a. and 2.3-1b.) have been considered. They have been named:

1. Old single space station common module design
2. New single space station common module design
3. Double space station common module design
4. Tin can design.

From these four designs, the new single space station common module design was the one finally chosen for the lunar shack. The decision was based on the decision matrix shown in Table 2.3-1.

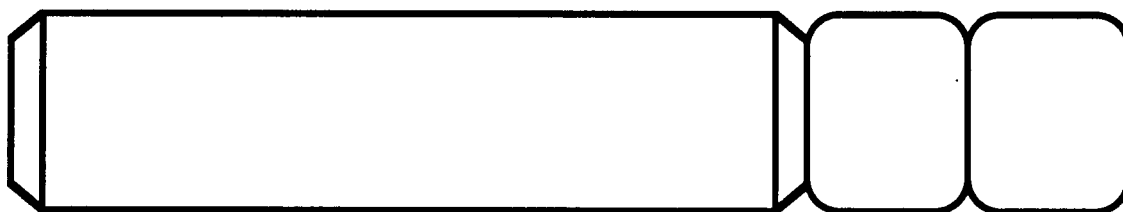
The difference between the old and new single common module design is that the new module has an airlock on either side of the module. This configuration gives a better distribution of mass for landing and better EVA capability than the old single module design.

The double module design uses two space station common modules. The tin can design is basically a three story cylinder with about the same interior volume as a single space station common module. The biggest problem of the double module design is that it has twice as much mass as the other designs and would be more difficult to launch and assemble. The tin can design seems to have some uncertainties in terms of structural integrity and radiation protection. Construction of large space vehicles, large enough to handle the tin can, would be a major consideration.

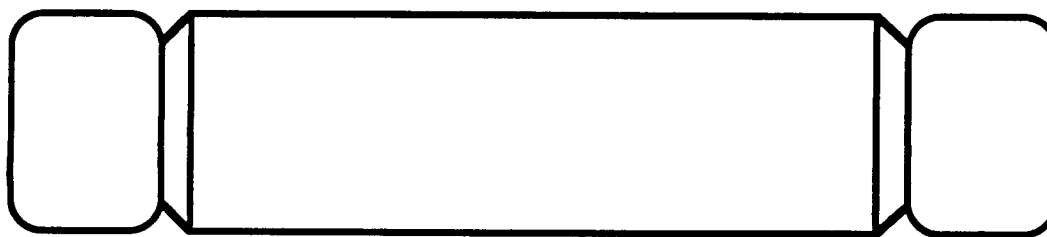
After evaluating all the design options, the new single common module design was chosen to be the best among the four. However, the tin can design was judged to be worthy of further study in order to more fully understand the potential of the design.

The decision matrix used to choose between the designs was formed by listing the requirements for the design and giving them weighting factors. The criteria were selected to include as many aspects of the design and performance considerations as possible. The weighting factors were based on the judgement of SEC's engineering team. The order of importance among the criteria was determined by the method of pairs. Once the order was determined, the criteria were divided into three groups according to the importance. Weighting factors of 40 to 50 were given to

DESIGN OPTIONS

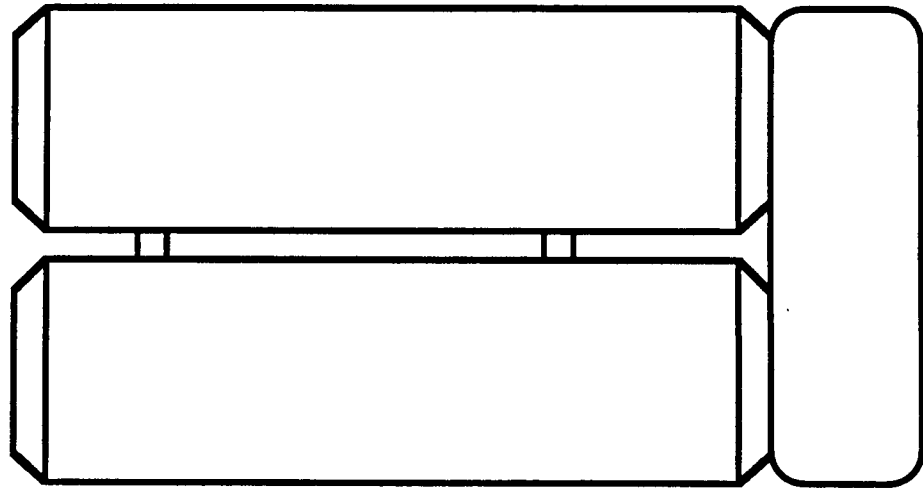


OLD SINGLE MODULE

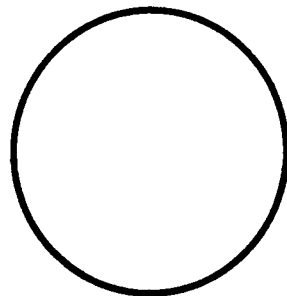


NEW SINGLE MODULE

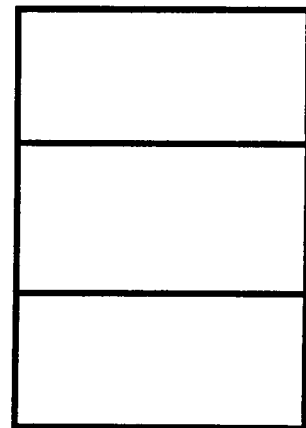
Figure 2.3-1a



DOUBLE MODULE



TOP VIEW



SIDE VIEW

TIN CAN

Figure 2.3-1b

CHOSEN CONFIGURATION

NEW SINGLE MODULE

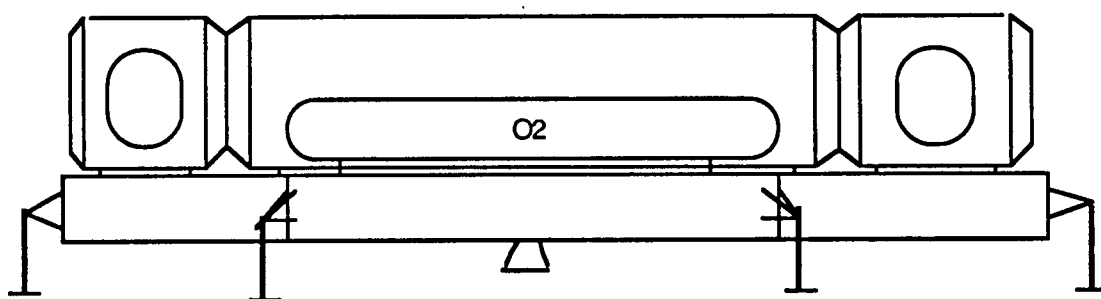


Figure 2.3-2

Table 2.3-1

CRITERIA	WEIGHING FACTOR	OLD SINGLE MODULE	NEW SINGLE MODULE	TIN CAN	DOUBLE MODULE
STRUCTURAL INTEGRITY	50	7	10	6	10
MASS	45	10	10	9	5
RADIATION PROTECTION	45	10	10	3	10
LAUNCH & ASSEMBLY	40	10	10	5	5
EVA	35	6	10	7	10
EXPANDABILITY	25	8	10	5	6
LIVING SPACE	20	5	5	6	10
EASE OF RESUPPLY	20	5	6	10	8
DESIGN FLEXIBILITY	15	6	6	10	8
STORAGE SPACE	10	5	5	4	10
REDUNDANCY OF 2ND SYSTEM	10	5	5	5	10
LOCATION OF MASS C.G.	10	3	5	10	7
SIZE OF SAFEHAVEN	5	5	5	2	10
BURYING TIME	5	7	8	10	3
TOTAL		2440	2925	2130	2690

(1 WORST → 10 BEST)

DECISION MATRIX

the first group, 20 to 35 to the second group and 5 to 15 to the third group. Then, a specific weighing factor was given to each criterion by the engineers. For each design, scale factors of 1 to 10 were given for each criterion. A scale factor of 10 was given to the best design and scaled down for the other designs. Total score of each design was obtained by multiplying the weighting factor by the scale factor and summing over all the criteria.

3.0 SPACECRAFT ENGINEERING

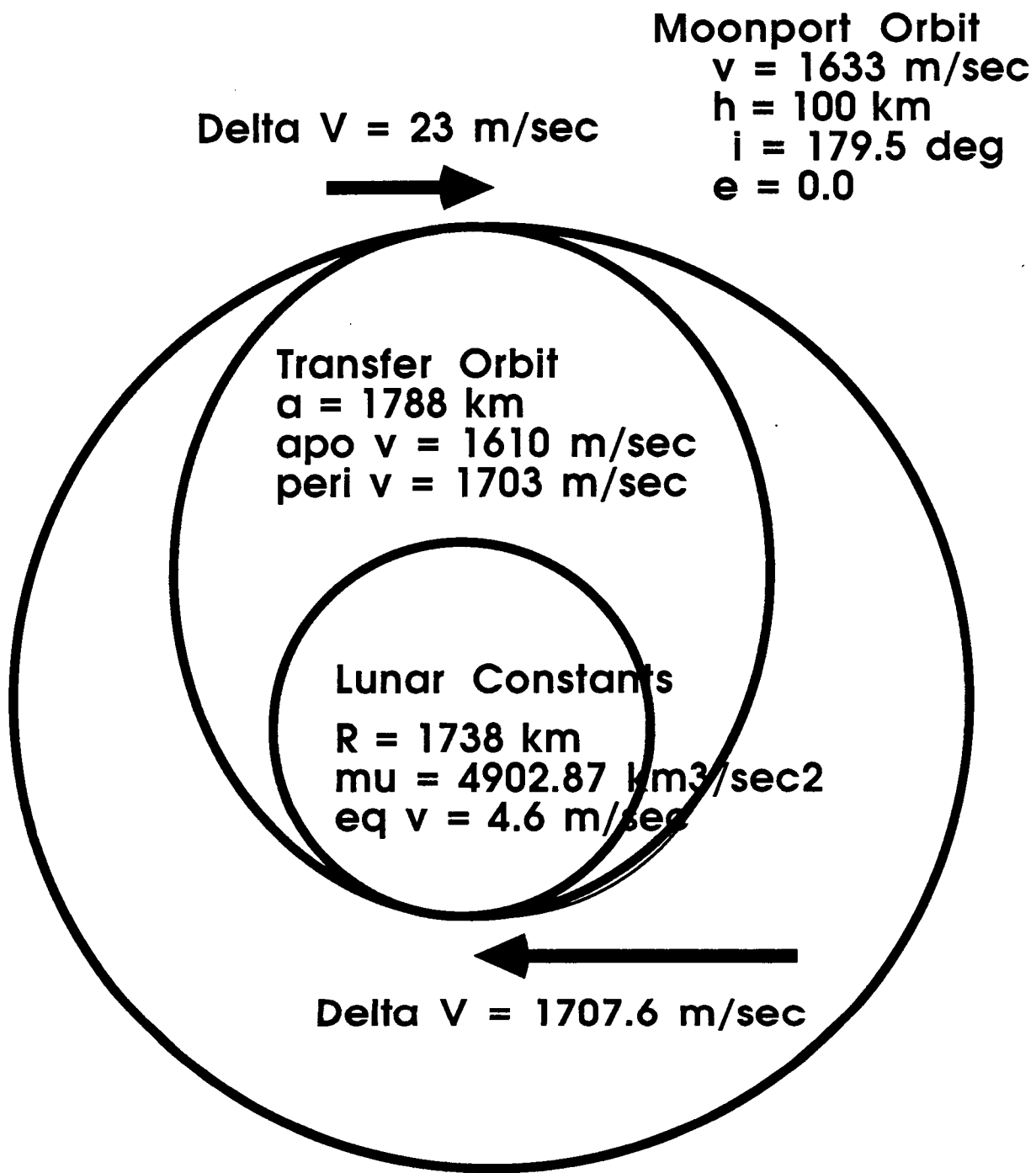
The shack, assumed to have arrived at Moonport (or the orbit that Moonport has been defined to use), must then be transferred to the lunar surface. Three parts of spacecraft design that are concerned with this end are: a general trajectory of the transfer from LLO to the lunar surface; the method (i.e., engines and propellants) to be used in propulsion of the shack; and the landing gear and surrounding lower stage, which absorb the shock of landing and support the shack after it has been lowered to the ground.

3.1 Velocity Changes

The Moonport's orbit is defined as a circular, equatorial, retrograde orbit with an altitude of 100 km. (Ref: Othon, W., et. al.; and Davis, G., et. al.) To facilitate the burn sizing, the shack will be assumed to land at an equatorial landing site on the lunar surface. A Hohmann transfer was used to define the required trajectory, so that propellant masses could be determined from the delta v's.

The calculations for these delta v's can be found in Appendix A (see also Fig. 3.1-1). The deorbit burn was found to be -23 m/s (positive is in the direction of the orbit), and the landing burn is -1708 m/s. After taking into account the rotation of the moon, the magnitude of the total change in velocity is 1731 m/s.

DELTA V's FOR LANDING



Total Delta V + 15 % = 1990.19 m/sec

Figure 3.1-1

3.2 Propulsion

The engine design chosen for the Lunar Shack Vehicle will be required to deorbit, hover and move about near the lunar surface during the landing phase of the mission. In order to perform these tasks the engines must be throttlable and gimbaled and must have a thrust to weight ratio of at least one at the start of the hover phase.

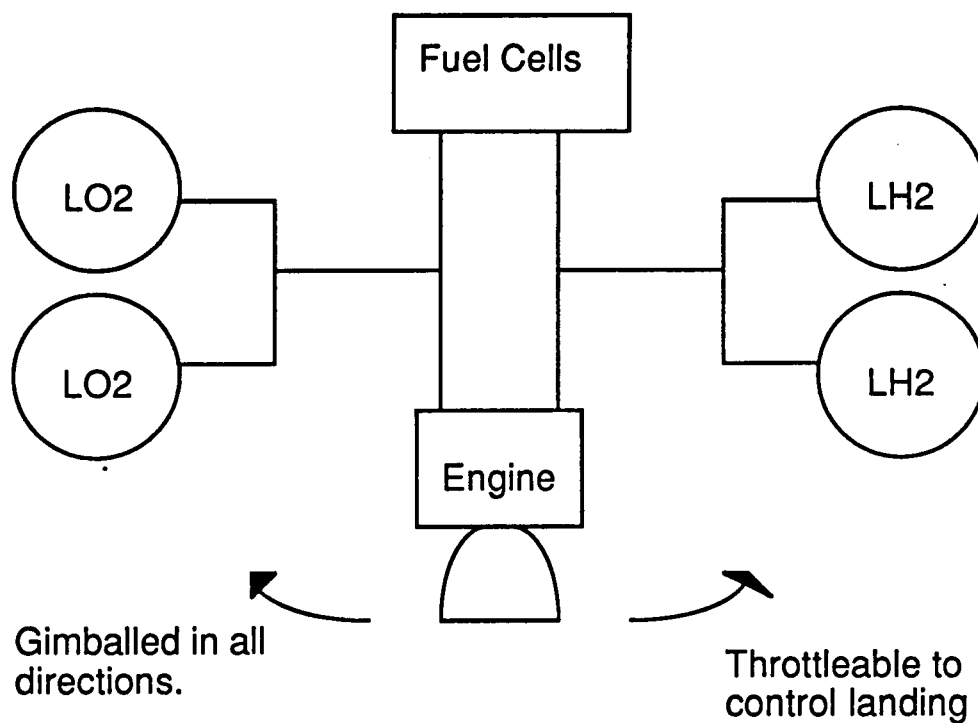
Two types of engines were considered, LO₂/LH₂ engines and storable propellant engines. Storable propellants such as hypergolic fuels do not require cryogenic storage and the technology is well established and understood. Liquid oxygen and hydrogen engines are less well established but they do have some distinct advantages. They have high specific impulses which reduce fuel mass requirements and they have the added benefit that any excess fuel, provided as a safety margin, could be used as a backup fuel supply for the fuel cells.

The LO₂/LH₂ engines were chosen because of the reduced mass requirements due to their higher specific impulse and the integration of fuel supplies with the fuel cell power system. Additional factors were considered but in almost all cases comparisons of the two engine types came out with small differences. Two additional points in favor of the LO₂/LH₂ engine were that the technology developed for the Shuttle could be used to produce throttlable LO₂/LH₂ engines for the Lunar Shack Vehicle and there is a possibility that the proposed Aerojet AJ10-199 reaction control system, which also is based on LO₂/LH₂, could be utilized on the Shack further integrating the fuel supplies.

The fuel calculations provided in Table 3.2-1 are rough estimates and are based on a number of assumptions. The calculations were performed on with a program written specially for this project. The calculations included here are based upon an assumed vehicle mass of 55,000 kg which is our estimate of the mass of the chosen design.

Table 3.2-1

Engines



Propellant: LO2/LH2

Thrust: 26700 lbf. (from MoonLander Program)

Specific Impulse: 450 s

Total Propellant: 61650 kg.
Includes a reserve of 8040 kg and
a very long hover time (10 min.)

Calculations Based on vehicle dry wt. of: 55000 kg.

3.3 Lower Stage

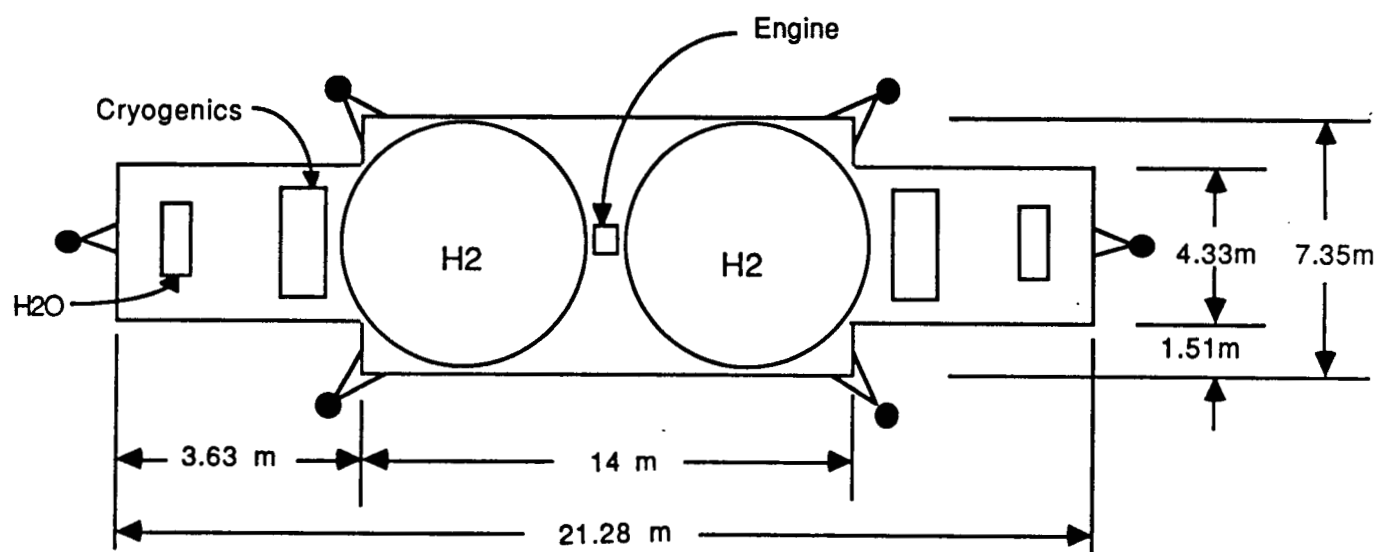
The purpose of the lower stage is to: 1) Distribute the landing forces exerted by the shack to the landing gear, 2) Provide a support structure for both landing and permanent habitation, and 3) House the engine, propellant tanks, water tanks, tank insulation, cryogenics, and piping to connect the tanks to the interior of the shack. The dimensions and layout of the lower stage are seen in Figure 3.3-1.

The lower stage will be constructed as a truss structure which will distribute the loads to the landing gear during touchdown. This type of structure was chosen over a walled structure because the truss configuration is lighter and distributes the loads better than a walled structure. A truss structure is also easily strengthened by simply adding more members.

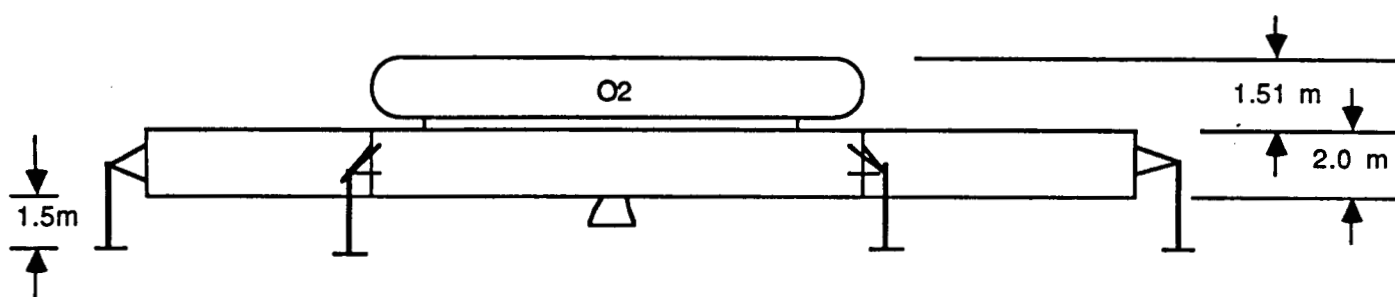
As seen in Fig. 3.3-1, part of the truss structure of the lower stage exceeds the width of the habitation module. This was done to alleviate the concern of maintaining zero moment about the vehicle center of gravity during descent. The habitation module's weight is mostly distributed along a single axis. This configuration would lend itself to producing torques about an axis perpendicular to that of the weight distribution if the correct descent path is not maintained. By providing some weight distribution along this perpendicular axis, these moments should be reduced. Also, this additional structure alongside the habitation module allows for the O₂ tanks to be placed on top of the lower stage. This increases the weight along the perpendicular axis and reduces the height necessary for the lower stage. The propellant tank shapes were chosen to make the most of the available space within the lower stage in this design.

Support pegs attached to the lower stage provide for permanent support and levelling of the habitation module. The pegs are individually mechanically adjustable so that the shack may be levelled.

Lower Stage



Top View



Center View

Figure 3.3-1

3.4 Landing Gear

The landing gear must absorb the shock of the landing. Other requirements of the landing gear are that it be lightweight, detachable, and reusable in the lunar base. It also must be able to lower the shack to the surface. Six landing gear are attached to the lower stage (Figure 3.3-1). Although four would be adequate to provide static stability, six landing gear struts provide a measure of redundancy in case one of them fails. The landing gear design, seen in Figure 3.4-1, consists of four structural elements which connect the lower stage to a mechanical jack. A seven member truss structure, also attached to the jack, makes up the lower vertical portion of the landing gear.

The landing pads will plastically deform to absorb the shock of landing. Thus, material selection is the key consideration to this design. Currently, the most likely candidate is aluminum honeycomb, because it has the plastic deformation characteristics desired and has been proven on the Lunar Module.

The seven member truss structure is bound and vertically oriented. The shack is lowered by means of a mechanical jack which is computer controlled to ensure that the shack remains level. In case of computer failure, the gear can also be lowered manually. The mechanical jack was chosen over a similar hydraulic jack because of the difficulty of maintaining an adequate seal on the pressure cylinder of the hydraulic jack in the vacuum environment of the moon. Also, a hydraulic jack could only lower the shack the length of the pressure cylinder. This would require the cylinder to be the length of the vertical members, which in turn would add unneeded mass to the structure. After the shack is lowered and levelled on the support pegs of the lower stage, the vertical members of the landing gear can be removed from the jack and separated for use as structural elements in the lunar base.

LANDING GEAR

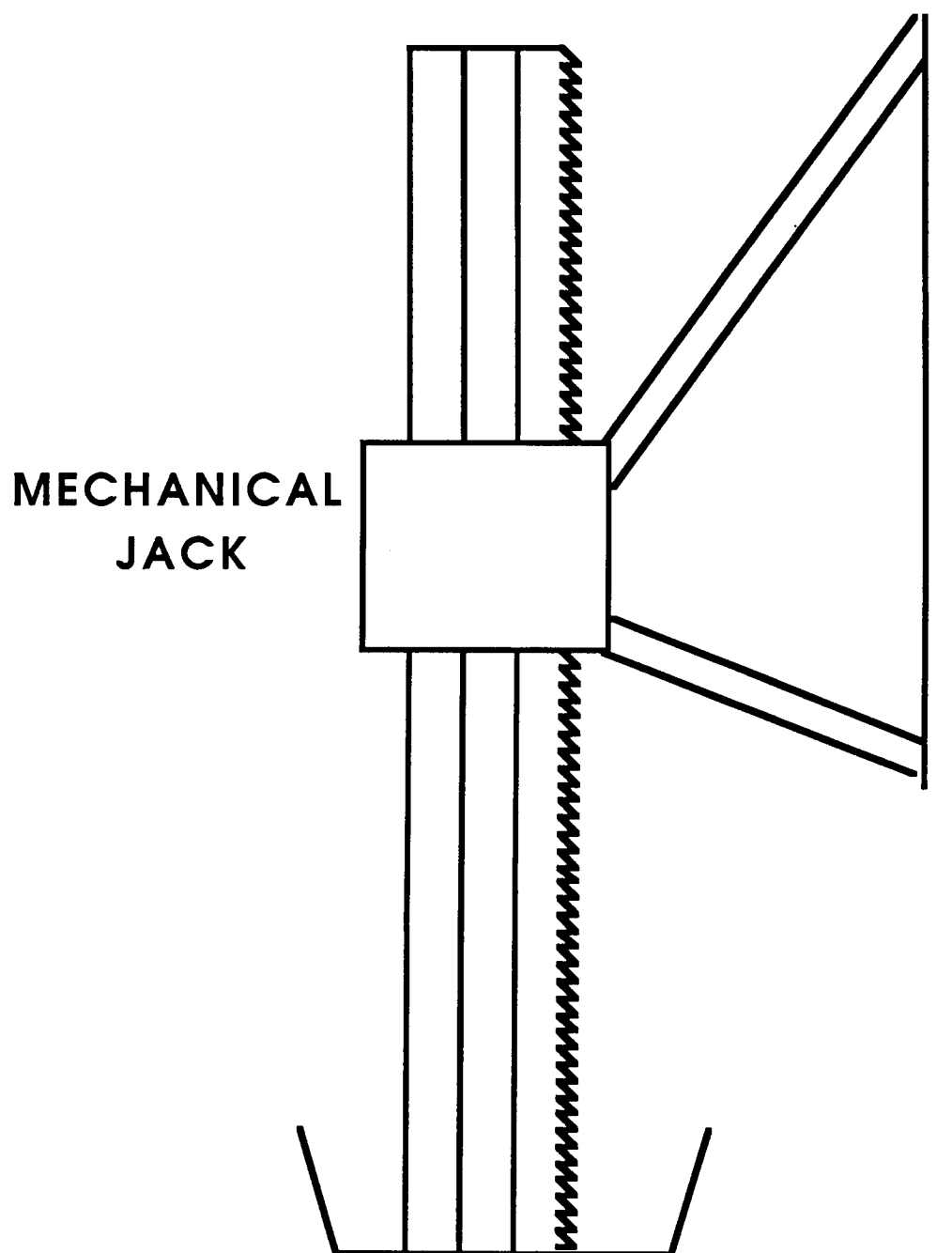


Figure 3.4-1

4.0 Human Engineering

4.1 Radiation

The types of radiation which must be shielded against are Galactic Cosmic Radiation (GCR) and Solar Radiation. Galactic Cosmic Radiation originates from the galaxy and usually consists of very low intensity high energy particles. GCR is omni-directional, which infers that humans must be shielded on all sides against it. Solar Radiation comes from the sun and usually consists of X-rays, high energy proton streams, ultraviolet radiation, and forms of radio interference. Of all types of radiation, ultraviolet radiation is the easiest and high energy particles are the hardest to shield against.

The most extreme cases of solar radiation occur during a solar flare. During a solar flare the Sun emits very high intensity radiation. This means an astronaut can receive a large amount of radiation, over 300 rems, in a short period of time, about two to three days. This dosage is enough to kill a human. Although solar flares occur about 6 to 7 times per year, the most dangerous flares, such as the those discussed above, happen in eleven year cycles. The years of high solar activity are expected to be: 1991, 2002, 2013, 2024. The initial mission to the moon should not be made during these years (Ref. Good).

4.1.1 Protection Against Nominal Radiation

Many options were considered for providing protection from the high radiation levels on the lunar surface. These options consisted of: totally or partially burying or covering the shack with lunar soil (regolith), bringing sufficient shielding from earth, or building a shelter over the shack and possibly covering this with regolith. These options were discarded because calculations show that the astronauts would receive only a small amount of radiation on the lunar surface for the short duration of their mission. Partially burying the shack was considered for making a safehaven, but this will be discussed later.

The total amount of radiation which the skin and bone of a person completely unshielded, standing on the lunar surface, would receive in thirty days during years of low solar activity are 1.56 rem for bone and 4.11 rem for skin. The amount of radiation a person would receive during

the transit time to and from the lunar surface which was estimated to be a maximum of 18 days was calculated to be 0.94 rem for bone and 2.47 rem for skin. The estimated total dose of radiation received yielded values of 2.50 rem for bone and 6.58 rem for skin. These calculations are shown in Appendix E. As is shown in Fig 4.1-1 these levels are far below the 30-day maximum dosage constraint. Thus it was decided that no radiation shielding, other than the material required to structurally support the vehicle, would be taken to the moon to protect against normal radiation levels. This conclusion requires that the initial mission be scheduled during years of low solar activity. These years are: 1996, 2007, 2018, 2029 (Ref. Good). The conclusion also assumes that after approximately 30 days the crew will either have constructed a better shielded habitat or the crew will be taken off the moon.

Again, the radiation dosages quoted above were calculated for a completely unshielded person standing on the surface of the moon. These dosages can be reduced. For instance, the structural materials chosen for construction of the vehicle can provide some shielding. A good candidate for this purpose is graphite-epoxy composite. Graphite is a natural for radiation protection because it slows high energy particles without producing a lot of harmful secondary radiation. The conventional aluminum materials are a problem for use as a structural material because they give off a lot of secondary radiation. Graphite composite structures can also be made such that they are stronger and lighter than comparable aluminum structures.

4.1.2 Protection Against Solar Flares

Provisions for protecting the astronauts from a solar flare are not critical if the mission is made during years of low solar activity. However, there is still the possibility of an unexpected solar flare or cosmic event, such as a super nova, which could cause a dangerous situation for the astronauts. It is not critical that the safehaven be immediately constructed upon reaching the lunar surface. This will be a judgement call which will be made depending on the situation at the time of the mission. Provisions for constructing a safehaven will be included in the shack design, but safehaven construction will be an optional part of an initial mission.

RADIATION CONSTRAINTS (in Rem)

	BONE	SKIN
30 - days	1.56	4.11
Transit time (18 days max)	0.94	2.47
Total dose	2.50	6.58
30 - day max rem constraint	25.00	75.00

Figure 4.1-1.

The options considered for providing a safehaven were: to totally bury the vehicle, partially bury the vehicle, or to "beef up" a portion of the vehicle with materials brought from earth.

The idea of total burial was discarded because of the complexities in shack operation this method would create. If the shack was completely buried it would need be buried at least 2.4 meters below the lunar surface because radiation levels actually increase until a depth of approximately 2.4 m is reached as shown in figure 4.1-2. This increase is due to secondary radiation given off by regolith. Because of the depth of burial, a passage to the surface must be built and maintained. Also because the thermal control system would need to have radiators on the surface, piping must be run down to the shack to circulate coolant fluid between the radiators on the surface and the vehicle. A totally buried shack also must have a modular communication system which must have cables running from the antenna on the surface down to the vehicle. Any problems with the piping or cables in these systems would be extremely hard to repair. It was concluded that total burial would create too many complications for an initial shack.

The chosen method for constructing a safehaven was a combination of partially burying and bringing materials from earth. The safehaven consists of burying the living areas while leaving the airlocks exposed. The vehicle must also have two shield walls located within the shack. The shield walls each have a sliding door which can be closed in case of trouble. The shack will be partially buried as shown in Fig. 4.1-3.

There must also be a shield collar around the vehicle to help reduce the amount of secondaries produced by the lunar soil. As was mentioned above, the amount of radiation received below the lunar surface actually increases due to secondary radiation given off by regolith. The level of radiation falls below the level on the surface at around 2.4 m depth (Ref. Guerra). This means that any path through the regolith which is shorter than approximately 2.4 m will have a large number of secondaries and thus a higher level of radiation. The collar is needed to slow down some of the high energy particles which follow the shorter path, before they reach the regolith. Thus the amount of secondary radiation given off on the short path can be reduced. This collar will be removable if it is deemed unnecessary to construct a safehaven.

DOSE EQUIVALENT PER YEAR (rem)

DEPTH OF • SHIELDING	GALACTIC (SKIN AND BONE)	MAX. SOLAR (SKIN) (BONE)	AVE. SOLAR (SKIN) (BONE)	TOTAL (BONE) (max sol) (ave sol)
Surface	12	319	38	47
4 cm	27	31	4	35
30 cm	78	2	--	79
1.0 m	32	--	--	32
2.4 m	7.5	--	--	7.5
3.8 m	0.7	--	--	0.7
5.2 m	0.1	--	--	0.1

* Shielding of lunar material in addition to an assumed 1.0 gm/cm² (aluminum equivalent) habitat.

Figure 4.1-2 YEARLY AVERAGE DOSE EQUIVALENTS FOR
GALACTIC AND SOLAR RADIATION AT AND
BELOW THE LUNAR SURFACE (Guerra, 1987)

SAFEHAVEN CONFIGURATION

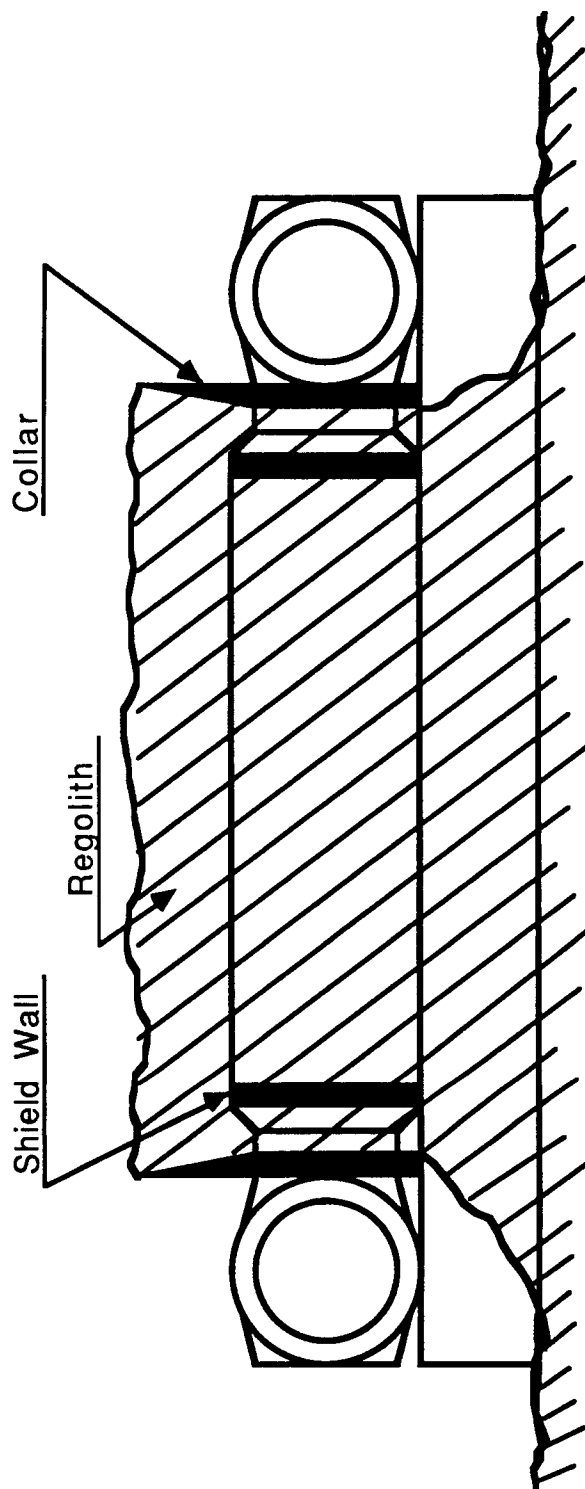


Figure 4.1-3.

The collar will be a circular disk cut diagonally in half which fits around the shack, as shown in Figure 4.1-4. It is made of graphite epoxy composite and weighs approximately 8923.34 kg. Thus the two collars required in the design will weigh 17846.68 kg.

The shield wall will be made of a composite of graphite composite and lead. It was found that by using a composite of different materials it was possible to get a lower weight while still receiving the same amount of protection. However, it was very difficult to determine how much shielding would be required to shield against a solar flare. Thus the actual mass of the shield wall will need further study. An estimate of a shield wall ten inches thick made of graphite epoxy resulted in a weight of 9786.62 kg. The two shield walls required by the design weigh a total of 19573.25 kg.

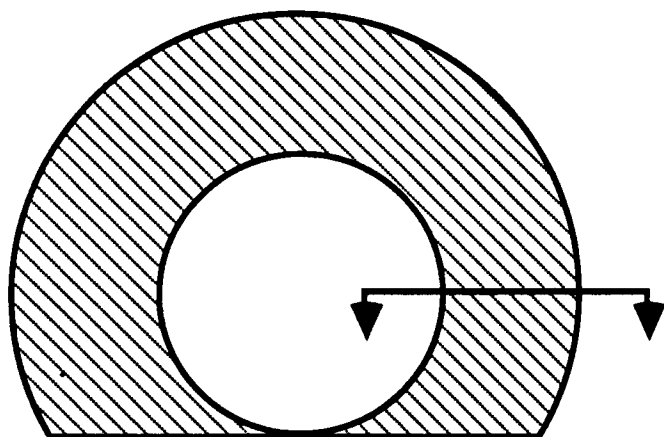
The estimated time needed to construct a safehaven, is 58.80 hours. This estimate was made under the assumption that a lunar soil mover developed by Georgia Tech which moves $260 \text{ m}^3/\text{hr}$ will be available (Ref. Georgia Institute of Technology). This number seemed a little high so a 25% efficiency of the mover was assumed. The efficiency was then decreased to 10% to allow for construction difficulties such as smoothing of regolith and collection of regolith from different sites around the shack.

4.1.3 Warning Systems

Warning systems will be required on the shack vehicle to warn the astronauts in case a solar flare occurs. A characteristic of solar flares is that during the first five minutes of the flare, the brightness of the sun increases. This is called the preflash of the flare and lasts about 5 to 20 minutes (Good, R.C. 1965). After the flare begins high energy particles will reach the moon's orbit, when the moon is closest to the sun, about 8.5 hours later. Taking into account message delays, such as communication time between the earth and moon, the astronauts will have approximately 7.5 hours to reach safety after warning is received. However, if there is a loss of communications for this period of time, the astronauts will have no prior warning at all. Thus a system on the shack which monitors the intensity of the sun's light is needed.

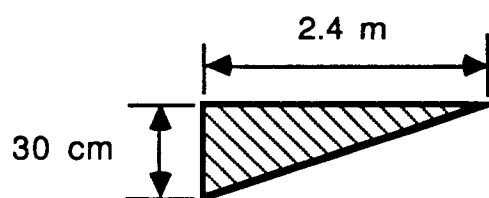
The system will consist of either 6 sensors which will be mounted on the airlocks, one on top and one on each side, or sensors which may be set

SHIELD COLLAR



Outer radius = 4.56 m

Inner radius = 2.16 m



Material: Graphite composite

Weight Estimate: 8923.34 kg

Figure 4.1-4.

out on the lunar surface. These sensors will send data back to a computer in the command and control area. An alarm will sound if there is a sharp increase in the sun's brightness.

The only problem with this system is that it cannot monitor the sun when the shack is on the side of the moon opposite the sun. Thus there will also be a sun monitoring system like the one above on the moonport which relays data down to the shack. There will also be a small satellite with sensors mounted on it, positioned 180° around from the moonport which orbits the moon at the same angular rate as the moonport. This satellite may also double as a communications satellite. The arrangement of the system will insure that at least one set of sensors will be able to monitor the sun at all times.

If somehow the preflash warning is missed, the next warning will occur when high energy particles begin arriving. Thus there should also be sensors which monitor radiation levels and send data to the command and control area of the shack. The system will sound alarms if there is a sharp increase in the radiation level. A set of sensors should be on the moonport, orbiting satellite, and shack vehicle.

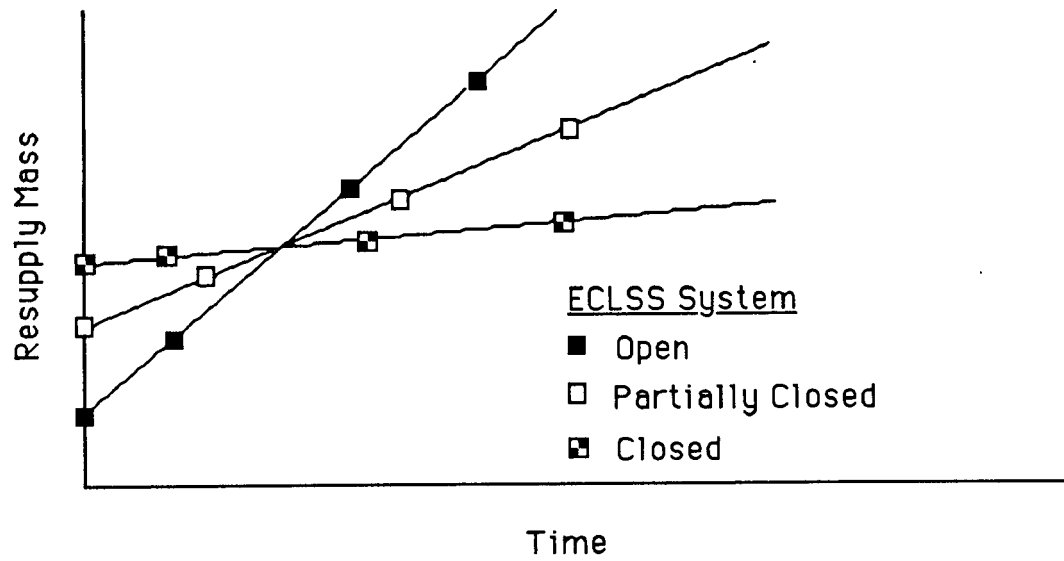
4.2 Environmental Control and Life Support System

The normal assumed crew rotation of three weeks assumes implemented systems within the spacecraft to provide a livable environment and protection from the lunar vacuum existing outside. This is the function of the Environmental Control and Life Support System (ECLSS). It will provide and maintain a breathable atmosphere for the crew and offer contingencies and redundancies in the event of an emergency.

4.2.1 System Analysis

In analyzing the various methods in which the ECLSS may function, one critical criteria had to be investigated first; that of how independent the system would be of resupply. Further considerations would follow, including impacts on mass and power requirements. Three candidate methods appeared as viable options, these being a Completely Open System, a Partially Closed System, and a Completely Closed System (See Figure 4.2-1). The Completely Open System was discarded as impractical, for it assumes all atmospheric consumables, once used, are either stored as wastes or evacuated to the exterior. Transportation costs to and from the moon are much too high to completely supply the quantities of the required oxygen, nitrogen, and other gases for every crew. Also, transportation of carbon dioxide, water molecules, and other waste products from the moon would be equally expensive. Although the Completely Open System would rely on its simplicity, requiring less power consumption and initial mass, it never-the-less was rejected for the Lunar Shack because of its high dependance on resupply.

The Partially Closed System, in which some atmospheric consumables are regenerated and returned to the spacecraft, was also investigated. In this system, Lithium Hydroxide cells would be used to remove any carbon dioxide from the cabin air. This system has been widely used in previous United States spacecraft, namely Mercury, Gemini, Apollo, and Space Shuttle. However, these spacecraft rarely exceeded a two week flight lifetime, far less than that expected of the Lunar Shack. Due to the fact that the carbon scrubbing process was developed for short spaceflights, it is thus viewed as inadequate for the purposes of the Lunar Shack.



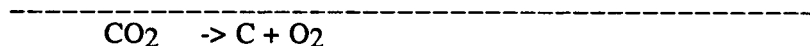
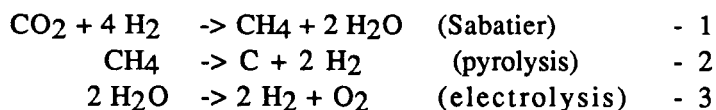
Candidate ECLSS Resupply Comparison

Figure 4.2-1

Although more complex than the previous two methods, the Completely Closed System was chosen for its attributes of nearly total atmosphere regeneration, requiring very little resupply and waste removal. Most of the oxygen is recycled and recirculated through the spacecraft in the following procedure:

- 1) Separation of carbon dioxide from the atmosphere
- 2) Decomposition of carbon dioxide into its elementary constituents; solid carbon and gaseous oxygen
- 3) Delivery of oxygen to cabin atmosphere
- 4) Disposal or stowage of carbon

A series of three chemical reactions will promote this conversion. These are, in order, the Sabatier reaction, pyrolysis, and electrolysis (Ref : Faget). The Sabatier reaction mediates the conversion of carbon dioxide and molecular hydrogen into methane and water. The methane is further reduced to solid carbon and molecular hydrogen by pyrolysis. The remaining water is converted to gaseous oxygen and hydrogen by the method of electrolysis (similar yet opposite to the process carried about within the spacecraft's fuel cells, where molecular oxygen and hydrogen are combined to create water). The procedure is shown graphically below:



Except for a small initial supply of hydrogen required to initiate the procedure, hydrogen would be regenerated by the process (results of 2 & 3). Also, the extracted carbon may be used to augment the spacecraft's radiation protection.

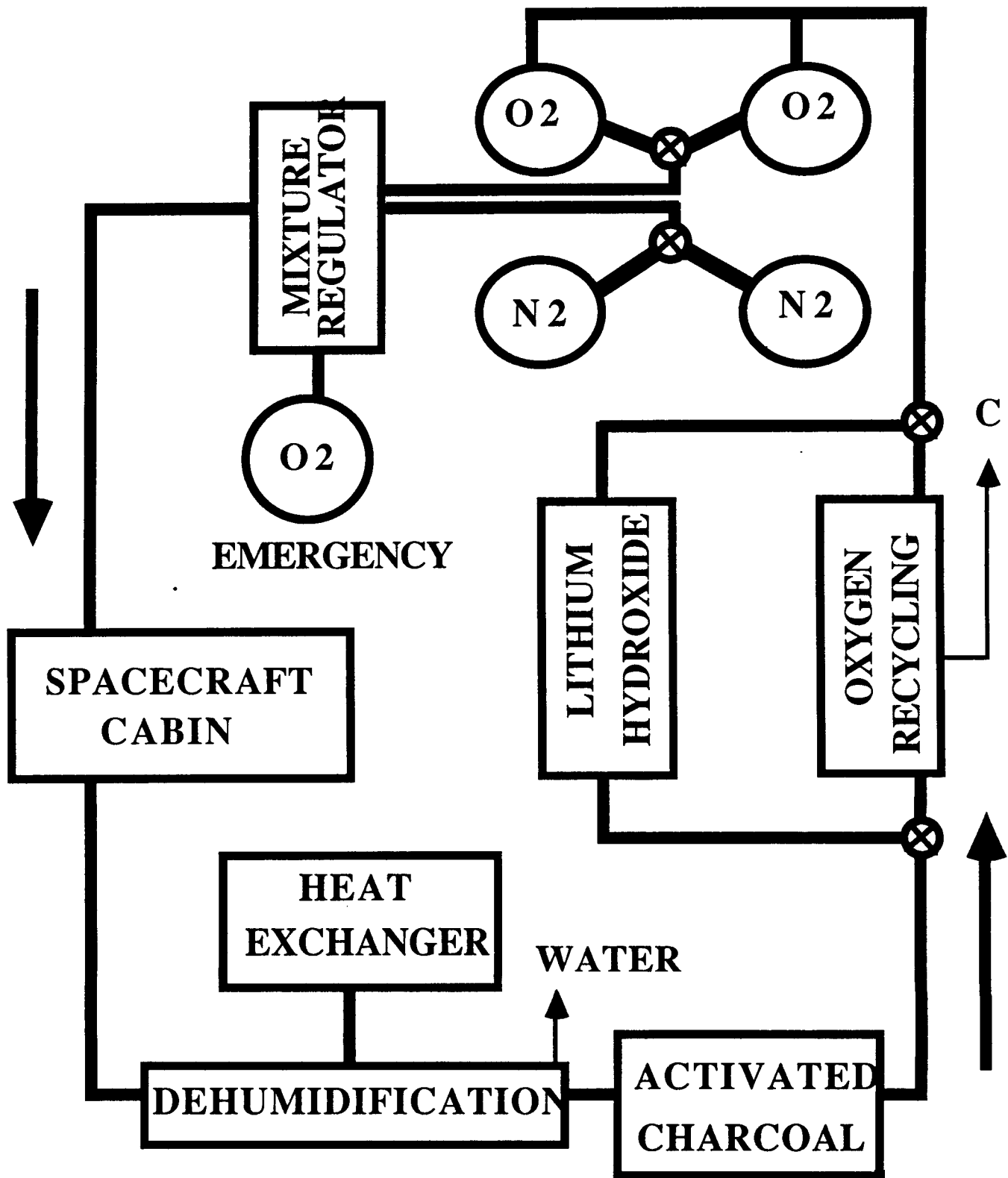
4.2.2 System Overview

The atmosphere within the spacecraft cabin is regulated at a 20 percent oxygen - 80 percent nitrogen mixture at a nominal pressure of 12 pounds per square inch (psi). A nominal sea level pressure of 14.7 psi is not considered mandatory; reducing the overall pressure to 12 psi, similar to 5,000 feet altitude, and maintaining a sea-level oxygen partial pressure

will help reduce the overall spacecraft mass. The incoming atmosphere will enter through vents situated about the cabin and circulated by fans. These will be unilaterally vented ports allowing air flow in only one direction, that being into the cabin, by the use of hinged flaps. The mass flow through each vent will be monitored by the ECLSS. If there are indications of excess mass flow (for instance caused by cabin wall puncture and loss of environment) or insufficient mass flow (by mechanical or system fault), alarms will sound in the cabin to alert the crew. Interior pressure is similarly monitored; oxygen partial pressure is maintained at between 2.95 and 3.45 psi (Ref. Press Information: Space Shuttle Transportation System), with sufficient nitrogen supplemented to achieve a total cabin pressure of 12 psi. All atmospheric values are monitored by onboard automation systems and can be viewed from instrumentation in the command section.

Oxygen is obtained from three sources; a primary and a secondary oxygen storage supply and an emergency oxygen supply (see Figure 4.2-2). The primary and secondary supplies each contain approximately 100 pounds of oxygen pressurized to approximately 2,000 psi. Each crew member can be expected to consume an average of 1.76 pounds of oxygen per day, or a total of 14.08 pounds per day for the crew (Ref. Press Information: Space Shuttle Transportation System). Some losses must be expected in the ECLSS due to: bleeding from the cabin to space, inefficiencies in the ECLSS, and repressurization of the airlock. A 200 pound supply of oxygen should be adequate for a crew of eight for the required 21 days. The nitrogen is obtained from a primary and a secondary nitrogen storage supply, each containing 150 pounds of nitrogen at an approximate pressure of 2,000 psi. The oxygen and nitrogen primary and secondary supplies may be used alternatively by discretion of the crew, actuated by cross-over controls in the command section. The emergency oxygen supply contains 20 pounds of oxygen, and will provide a cabin pressure of 6 psi at an oxygen partial pressure of 2 psi.

Humidity levels will be maintained at a 20 % saturation level to augment crew comfort while maximizing protection of flight avionics and other electronic equipment and minimizing condensation levels on cabin walls and interior. The Humidity Control System (HCS) is composed of three elements: the condenser, water collector and separator. The



SPACECRAFT ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

Figure 4.2-2

condenser is a simple heat-exchanger sink plate (for further information reference Section 4.3 : Thermal Control and Heat Management System) which precipitates the water from the air. Water is collected by the combined effects of gravitational force and water absorption devices. Once separated, the air is transported to be recycled and the water sent to the waste management system.

Various sensors will monitor the cabin environment continually. Alarms within the cabin will be set off in the event of any of the following events:

Cabin pressure below 12.0 psi. or above 12.6 psi.

Oxygen partial pressure below 2.8 psi. or above 3.6 psi.

Humidity level below 18 % saturation or above 22 % saturation

In each circumstance, set planned procedures and spacecraft specified rules will be implemented to correct the problem. In the ECLSS cycle, once air exits the cabin, it is passed through the HCS and into an activated charcoal filter to remove odors and other environmental hazards. A small nonregenerative supply of lithium hydroxide will be incorporated into the system in the event of serious malfunctions in the ECLSS. It will have the capability to remove exhaled carbon dioxide for a period not to exceed the emergency oxygen supply.

The total power consumption of the ECLSS is expected to be 4 kilowatts (kW) (Ref. Guerra). The Sabatier reaction requires 1.55 kW per pound of oxygen recovered. The system will produce 3.12 kW of waste heat and have a launch weight of approximately 2000 kilograms (kg). It will require on the average of 38 hours of maintenance and monitoring for the mission duration of 21 days.

4.3 Thermal Control and Heat Management

In considering a design for a spacecraft located on the surface of the moon, a Thermal Control System must be incorporated to : 1) regulate and maintain a comfortable, workable, and livable temperature level within the spacecraft cabin, 2) collect and transfer any excess heat, and 3) dissipate this heat efficiently. Before investigating and conceiving methods to conduct these operations, a brief understanding of the temperature and related physical characteristics of the lunar surface is requisite; this is necessary for all designs must work within these limits. Some features are listed below:

HIGHEST SURFACE TEMPERATURE.....	273 F
LOWEST SURFACE TEMPERATURE.....	-243 F
ROTATIONAL PERIOD.....	27 DAYS, 7', 27"
ALBEDO.....	0.07
EMISSIVITY.....	0.96
MAXIMUM SURFACE ABSORBED HEAT FLUX.....	1300 W/M2
MAXIMUM SURFACE RADIATIVE HEAT FLUX.....	1100 W/M2

These values are consistent for Mare or lowland regions; differences must be expected due to variations in Lunar geology, surface features, and local terrain.

4.3.1 Spacecraft Heat Collection Systems

The spacecraft temperature is maintained by the ECLSS at between 65 F and 80 F at the discretion of the crew. Airflow is used to cool and collect heat generated from the crew, electronics, and other systems within the cabin volume. The air is cooled during the dehumidification process (refer to Environmental Control and Life Support System) by the use of Heat-Exchange Elements (HEE) or coldplates. The HEE are the spacecraft's primary heat collection devices, and are a sub-system of the Water Coolant Loop (WCL).

The WCL is a network of fluid flow loops within the spacecraft walls and system compartments. The thermal loads on the shack are similar to present day spacecraft, thus the WCL is modeled from the Water Coolant Loop system used in the Space Shuttle (all characteristics and numerical values are based upon this system). This network surrounds most heat

generating items, avionics and electronic bays, and passes through the HEE's. The Heat-Exchange Elements are metallic (chosen for their good heat conduction characteristics) flat plates, approximately 0.75 to 1.00 inches thick, in which water from the WCL flows through in a "switch-back" configuration of pipes. All avionics and other large equipment are placed and mounted on HEE's, the heat being transferred directly to the WCL. A primary water pump controls the mass flow rate of between 900 to 1,000 pounds per hour through the loop (Ref : Press Information, Space Shuttle Transportation System), regulated manually by the crew. Monitors are situated about the WCL maintaining proper system functions and water pressure. An outlet pressure monitor at the water pump surveys the WCL interior pressure, initiating a cabin alarm if this pressure should fall below 45 psi. or above 80 psi, inferring a system malfunction. A secondary pump and monitoring devices will be used in the system for extra reliability and redundancy in the event of a malfunction in the primary pump. The termination point of the WCL is the Freon Coolant Loop (FCL) where heat is transferred and the water returned to the WCL.

4.3.2 Spacecraft Heat Rejection Systems

The FCL is the primary heat rejection system for the Thermal Control and Heat Management System (TCHMS). Due to the toxic characteristics of the Freon-21 used in this system, the FCL is located outside the spacecraft cabin. There will be two FCL's, both to operate simultaneously, yet each has the capability to act independently and maintain system integrity if one should malfunction. The standard operational temperature is controlled to 38° F. The FCL is used to collect heat from the WCL.

The last step in the TCHMS is the dissipation of heat collected by the FCL. Initially, four candidate methods were investigated (see Figure 4.3-1). The first is a system consisting of Flash Evaporators. The Freon-21 is passed through a chamber where water or ammonia is sprayed. The heat is removed from the system as the water or ammonia evaporates and is vented to the environment. The Freon, now sufficiently cooled, is returned to the FCL. This system, although simplistic in nature, was ruled as impractical for the Lunar Shack due to its heavy dependance on evaporative material (estimates show a requirement of 42,000 pounds if

	W.F.	FLASH EVAPORATORS	RADIATORS	CONDUCTOR PLATE	WATER RESEVOIR HEAT EXCHANGER
MASS	8	1	3	7	8
EASE OF DEPLOYMENT	4	9	4	3	6
AVAILABILITY OF TECHNOLOGY	2	9	5	4	7
VOLUME	4	2	2	7	6
ABILITY TO DISSIPATE HEAT	5	6	8	2	7
TOTAL		100	98	114	161

THERMAL CONTROL DECISION MATRIX

FIGURE 4.3-1

water is used as an evaporant, this assuming an additional input of 7,200 pounds from active fuel cells (Ref. Press Information: Space Shuttle Transportation System)). This critical mass requirement is far too large for prudent use in our spacecraft.

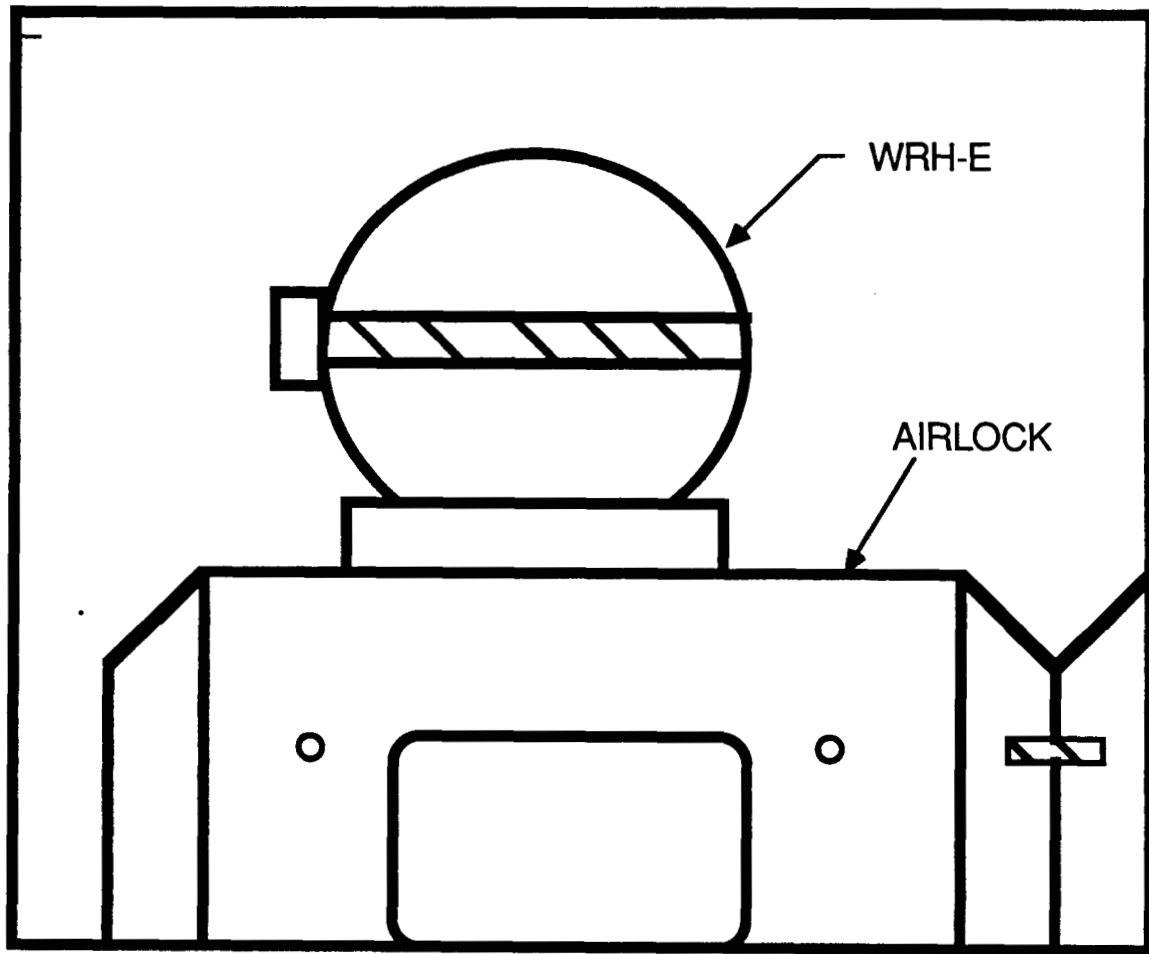
A second method is the use of radiators to dissipate heat. The FCL would pass through the radiators in a "switch-back" configuration, transferring the heat to be radiated to the lunar environment. This system was judged insufficient for our purposes for two reasons. First, radiative techniques are not effective during the lunar day without some further form of protection (i.e. a canopy). This would increase the mass (and therefore the cost) of what is to be a mass effective spacecraft. If the system were operated only during lunar night, some other method would still be needed for daytime heat dissipation. The second reason for discarding this technique is a required effective area of over 600 square meters of radiator surface (Ref. Guerra). Even utilizing both sides of a radiator, the mass and volume implications and construction methods are unreasonable.

The third method is the use of a conductor plate, constructed from "heat pipes", that is buried to a prescribed depth in the lunar surface. Ideally, the moon would be used as a "infinite heat-sink". Unfortunately, ideal conditions do not exist; the thermal conductivity values for lunar regolith are far too low to effectively dissipate heat.

Therefore, the method chosen is the use of Water Reservoir Heat-Exchangers (WRH-E). Two WRH-E are mounted on the spacecraft's airlock, one WRH-E on each airlock (Figure 4.3-2). The FCL passes through a horizontal pipe within each tank, entering and exiting through valves on the tank's surface (Figure 4.3-3). During lunar day, the tanks are used as heat reservoir elements for collecting excess heat from the spacecraft.

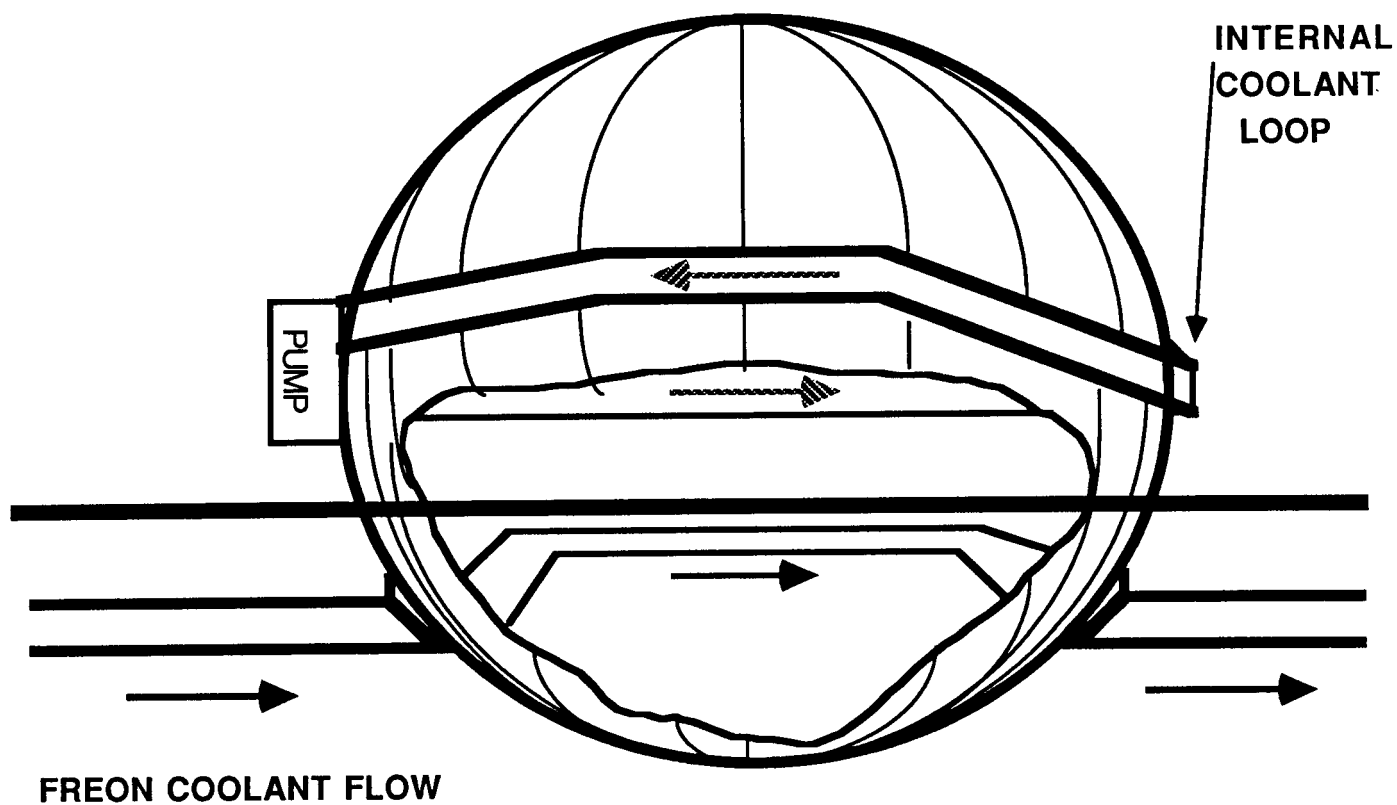
During lunar night, the tanks offer a dual role. If the heat generated by the spacecraft is insufficient to adequately maintain a comfortable temperature within the spacecraft's cabin, heat can be transferred from the tanks to the Shack through the FCL. If, however, this heat is not required, the tanks can dissipate their heat through an independent internal coolant loop exposed to the surface.

This closed loop passes through each tank horizontally and wraps around externally to complete the loop. It is maintained at a constant fluid



**LOCATION OF WATER RESERVOIR
HEAT-EXCHANGER**

FIGURE 4.3-2



WATER RESERVOIR HEAT EXCHANGER

FIGURE 4.3-3

pressure by a small pump activated from the command section. When night ends and day begins, the internal water temperature of each tank will be sufficiently cool to once again act as heat-exchange reservoirs. Each tank will need to be amply insulated, and is protected by thin, highly reflective light-weight coverings made from Mylar. The internal water is traced with Ethylene-Glycol to protect from freezing and boiling.

There are two independent Freon Coolant Loops to transfer spacecraft heat to and from the WRH-E, one for each the WRH-E. This is for redundancy in the event of a system malfunction, and to lessen the required length-of-path traveled by each FCL, thereby reducing internal fluid pressure.

Fluid pumps are located one each at the at the inlet and outlet connections, and two within the spacecraft (only one of these to be operational at only one time). If one pump should fail, the remaining three should be able to maintain system integrity.

4.4 Power Supply/ Power Storage System

4.4.1 Power System Design Selection

The primary power source for the Lunar Shack will be a nuclear reactor placed on the lunar surface to support the eventual lunar base. One of the first crew operations will be to bring this reactor on line. The reactor and its control and management instrumentation will be located in a suitable crater remote from the Shack's landing site. The crew will perform any necessary excavations and tests to initiate the reactor's operation. The crew will also lay cable between the reactor and a power conditioning unit located near the Shack. During these operations, an auxilliary power system will be needed to support the Shack's environmental and life support, thermal management, communications and secondary systems. This power system must satisfy the following requirements.

- * Power must be available immediately upon arrival of the crew.
- * The system must meet the Shack's estimated 45 kWe peak requirement (ref. Guerra).
- * The system must support the Shack and all external loads for at least one week while the reactor is being brought on line.
- * The system must supply backup power in the event the reactor fails or requires maintenace.

The secondary power supply system was chosen on the basis of its reliability, mass, volume, degree of setup required and its commonality with other on board systems.

Four candidate power systems were considered and each is listed in Table 4.4-1. The first design, which involved an on board nuclear reactor, was rejected because of difficulties in shielding the crew from radiation. Additionally, because nuclear systems have relatively high mass, they first become cost effective at power output levels above the 20 to 45 kWe required to supply the Lunar Shack (Ref. Advanced Nuclear Systems for Portable Power in Space). The second system, which utilized photovoltaic arrays and storage batteries, was rejected due to its high mass, high volume and because of the setup it required. The third system, a simpler one involving only nickel-hydrogen IPV storage batteries was considered

TABLE 4.4.1-1
POTENTIAL LUNAR SHACK POWER SYSTEMS

SYSTEM	MASS	VOLUME	PROBLEMS
On Board Nuclear Reactor	High	Low	<ul style="list-style-type: none"> * Radiation Concerns * Efficient systems too large.
Photovoltaic/ Batteries	High	High	<ul style="list-style-type: none"> * Setup Required
Batteries	Low	Low	<ul style="list-style-type: none"> * Low energy density * Low Depth of Discharge
Regenerative Fuel Cells	Low	Low	<ul style="list-style-type: none"> * Reliability concerns

because it has low volume, low mass, high efficiency and high reliability. The only problems with such a system are its low energy density and the batteries' low depth of discharge. The forth system, involving multiple regenerative fuel cell units (RFCs), was eventually selected because of its low mass, low volume, reasonable efficiency, and possible high energy density. Additionally, the RFC systems' reactant fuels, oxygen and hydrogen, which make up a large portion of its mass, are common fluids with the propulsion and environmental control and life support systems. This commonality allows the use of residual fuel in the propulsion system to generate power and also adds flexibility in the ECLSS by facilitating conversion between water and oxygen.

In 1984, United Technologies defined and characterized a 10 kW Engineering Model System demonstrator regenerative fuel cell unit (EMS RFC) utilizing 1991 baseline technology (ref.Garow). Table 4.4.1-2 compares the energy density (W-hr/kg) of the EMS RFC unit with those of nickel-cadmium and nickel-hydrogen battery systems. The EMS demonstrator unit has approximately the same energy density as the NI-H₂ system and offers the possibility of sharing its water and oxygen working fluids with the ECLSS. A 1983 Life Systems Corporation report indicates that weight optimized 10 kWe RFC modular units might be designed with energy densities approaching 90 W-hr/kg (ref.Chang). The United Technologies EMS RFC units are acceptable for use with the Lunar Shack, but with research, RFC units having higher energy density and efficiency could be developed.

The United Technologies Report cited four pacing technologies in RFC design which if improved, would increase RFC system reliability. These items were:

- * fuel cell endurance
- * endurance in stacks of large (1 sq. ft.) electrolyzer cells
- * hydrogen circulation pump bearing life
- * cyclic water pump bearing and seal life.

These technology items should not present problems in building a reliable power supply system for the Lunar Shack. An existing baseline fuel cell stack of six cells has already demonstrated 18,000 hours endurance. The

TABLE 4.4.1-2
POWER SYSTEM
ENERGY DENSITY

POWER SYSTEM	ENERGY DENSITY (w-hr/kg)
Engineering Model RFC System	28.46
Nickel-Cadmium Battery System	20
Nickel-Hydrogen Battery System	30

Source for data: Garow

Orbiter hydrogen pump has demonstrated 12,000 hours continuous endurance. And manufacturers for the RFC cyclic water pumps have indicated that the EMS RFC design requirements are not particularly severe. The electrolyzer cells pose the chief design problem for the RFC power system. A Life Systems Corporation optimization computer program showed that 1.0 sq. ft. alkaline electrolysis cells were within the optimal size range for 10 kWe RFC units. Because electrolysis cells of this size have yet to demonstrate endurance in stacks of more than six cells, their design will have to be improved.

The EMS RFC units were designed for use in conjunction with solar arrays on a satellite in low earth orbit (LEO). While the satellite was in sunlight, some of the power generated by the solar arrays was used in the RFC electrolyzer cells to split water into hydrogen and oxygen. While the satellite was in darkness, the RFC fuel cells combined the hydrogen and oxygen to generate water and electrical power. The EMS RFC units were designed to achieve a 40,000 hour lifetime while charging and discharging approximately every 90 minutes in the LEO environment. These RFC units will suffer much less wear and tear in the Lunar Shack power system. The RFC units will discharge continuously for as long as one week before being recharged by the lunar nuclear reactor. Thereafter, the RFC units will only need to operate as a backup to the reactor and possibly in conjunction with the ECLSS. Reliability in the Lunar Shack power system will be enhanced by including extra RFC modular units. These extra units will obviate the need of performing maintenance on an RFC unit which fails. The RFC units' modular design allows refitted RFC units brought to the moon by succeeding crews to be rotated into the power system.

4.4.2 Lunar Shack RFC Power Supply / Power Storage System

4.4.2.1 Operation

Figure 4.4.2-1 shows a schematic diagram of an RFC power supply / power storage system involving a single RFC modular unit. The actual Lunar Shack power system employs four RFC units. The Shack is to be landed on the moon with sufficient store of hydrogen and oxygen remaining in the propulsion system tanks to allow two RFC units to produce 10 kWe apiece for one week. Extra propulsion fuel will be carried to allow the Shack to hover during descent. It is possible that enough residual propulsion fuel will remain to allow all four RFC units to operate at 10 kWe each for as long as three weeks. During this discharge period, the fuel cells will generate water, which will be filtered and stored, and electricity, which will be sent to the power modulation and distribution unit (PMAD). The PMAD unit will condition the fuel cells electrical output and provide it to a dual ring bus power distribution architecture patterned after that of the proposed U.S. space station (ref. Bernatowicz).

Once the lunar nuclear reactor is brought on line, it will supply power through the external power conditioning unit directly to the Lunar Shack's PMAD unit. Relieved of their power supply responsibilities, the fuel cell units will cease to operate. Power from the reactor will then be diverted to the power system's electrolyzers which will split a portion of the stored water back into hydrogen and oxygen. Once this process is complete, the stored hydrogen and oxygen will represent 168 hours of backup power in the event the reactor fails or requires maintenance. The charge/discharge process can be repeated as necessary.

The RFC power system's fuel cells can be used to transform excess propulsion fuel into water which can be filtered for use by the crew in the showers and toilets. If necessary, the power system's electrolyzers can later be used to extract oxygen from this stored water. Table 4.4.2-1 shows the reactant and water consumption and production rates for operations modes with two and four RFC units operating nominally at approximately 10 kWe. The power system allows flexibility in the operation of the Environmental Control and Life Support System and this enhances the crews safety.

FIGURE 4.4.2-1
RFCS MODULE SCHEMATIC

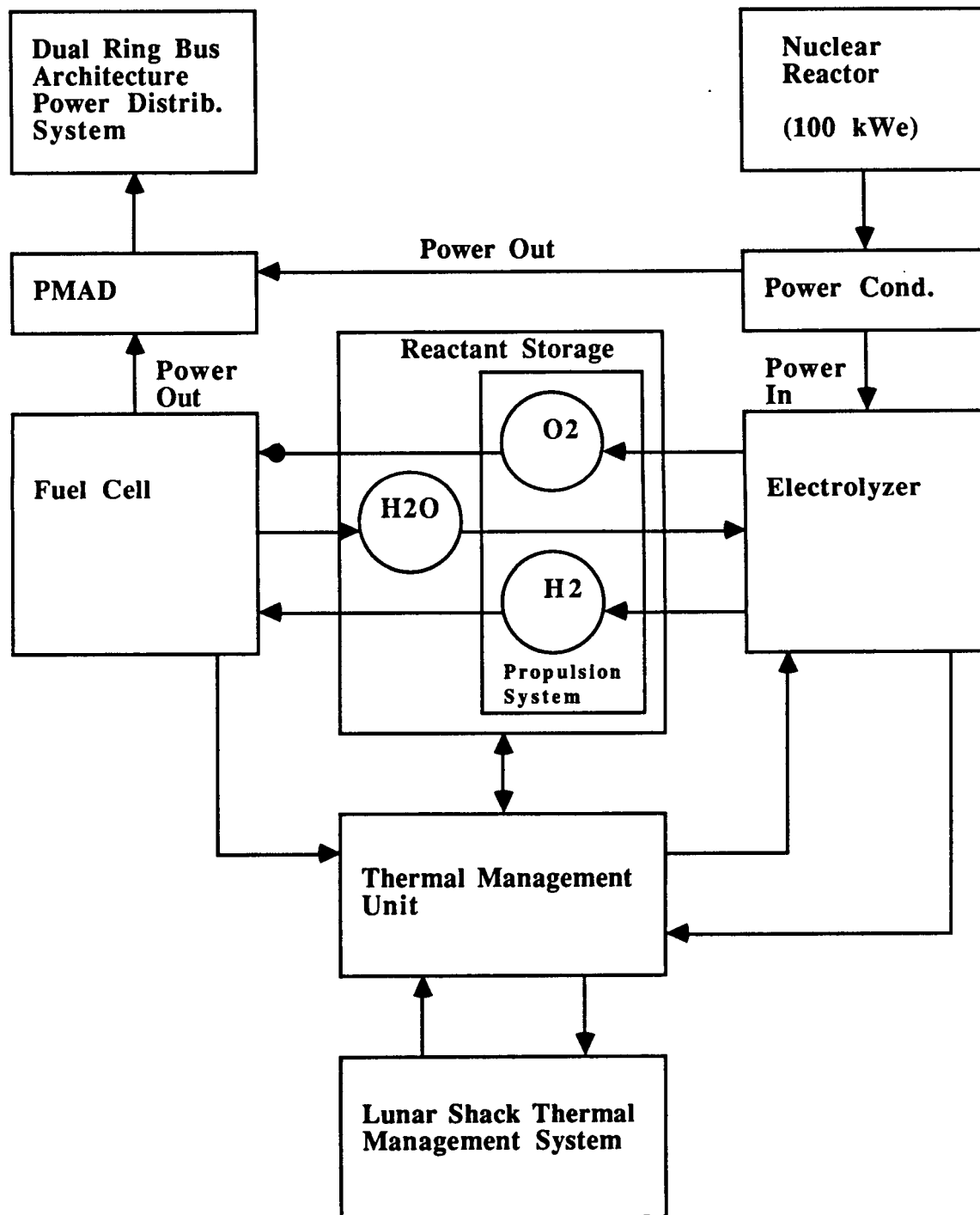


TABLE 4.4.2-1
RFC POWER SUPPLY / POWER STORAGE SYSTEM
OPERATING CHARACTERISTICS (at 10 kW)

	2 Active RFC Units	4 Active RFC Units
CHARGE MODE:		
H2 PRODUCTION (LBS/HR) (KG/HR)	1.37076 0.62177	2.74152 1.24352
O2 PRODUCTION (LBS/HR) (KG/HR)	9.4418 4.2826	18.8836 8.5652
H2O CONSUMPTION (LBS/HR) (KG/HR)	12.7838 5.7986	25.5676 11.5972
DISCHARGE MODE:		
H2 CONSUMPTION (LBS/HR) (KG/HR)	2.0798 0.9493	4.1596 1.8868
O2 CONSUMPTION (LBS/HR) (KG/HR)	15.4556 7.0106	30.9112 14.0212
H2O PRODUCTION (LBS/HR) (KG/HR)	17.5464 7.9588	35.0928 15.9176

Source for data: Garow

4.4.2.2 System Characteristics

In order to keep water vapor from condensing in the reactants, both the electrolyzers and fuel cells have 180° F operating temperatures. In the fuel cells, a dielectric coolant circulates through the condensor and cooler assemblies of the power section. The coolant carries heat to the heat management unit where it is exchanged with the Lunar Shack heat management system. A bypass loop in the heat management unit allows the dielectric coolant to be diverted to the electrolyzers to maintain them at 180 F. In the recharge mode, in which the electrolyzers split water, either the fuel cells could be run at low levels to heat the electrolyzers or heat could be supplied by the Shack's heat management system.

The RFC power system reactant and water storage tanks are remote from the RFC units. Hydrogen and Oxygen will be stored in the propulsion system tanks and water will be stored in tanks accessible to the Shack's showers and toilets. Reactants will be supplied to the power sections of the fuel cells by a demand type pressure regulator. This regulator unit will maintain pressure in the power sections over a range of reactant flows. A demand type regulator also will be used to control the flow of water to the water feed pumps in the electrolyzers. Small reservoir tanks for the incoming reactants and water will be kept filled and will be maintained at the RFC units' 180° F operating temperatures.

Tables 4.4.2-2 and 4.4.2-3 show the physical and electrical characteristics of a United Technologies Engineering Model System regenerative fuel cell modular unit.

Each unit weighs about 209 kg and nominally provides approximately 10 kWe. Higher output levels up to about 30 kWe peak are possible for each unit but are accompanied by higher reactant consumption rates. The fuel cells produces 100 v dc and the electrolyzers require power input at 100 v dc. The dimensions of the RFC units are defined and are compatible with both the primary common module based and secondary "tin can" Lunar Shack designs.

The Lunar Shack power system employs four modular RFC units which are placed within the common module beneath the floor of the galley. Figure 4.4.2-2 shows the layout of the RFC units. The units are paired and and share electrolyzer output water filters. Reactants and water are stored exterior to the common module and are passed to and from the RFC units

TABLE 4.4.2-2
RFC MODULE PHYSICAL CHARACTERISTICS

ELECTROLYZER		FUEL CELL	INTERFACE TO REACTANT STORAGE UNIT	TOTAL FOR RFC MODULAR UNIT
WEIGHT (ILBS) (KG)	203 104.3	145 65.8	113 51.3	461 209.1
DIMENSIONS (HxWxL) (FT) (M)	- -	- -	- -	1.75 x 2.33 x 2.5 .533 x .710 x .762
# CELLS	33	116		
CELL AREA (FT**2) (M**2)	1.0 0.092	0.508 0.047	- -	- -
TEMPERATURE (F)	180	180	180	-
PRESSURE (PSIA) (KN/M**2)	300 2.068E6	60 4.137E5	- -	- -

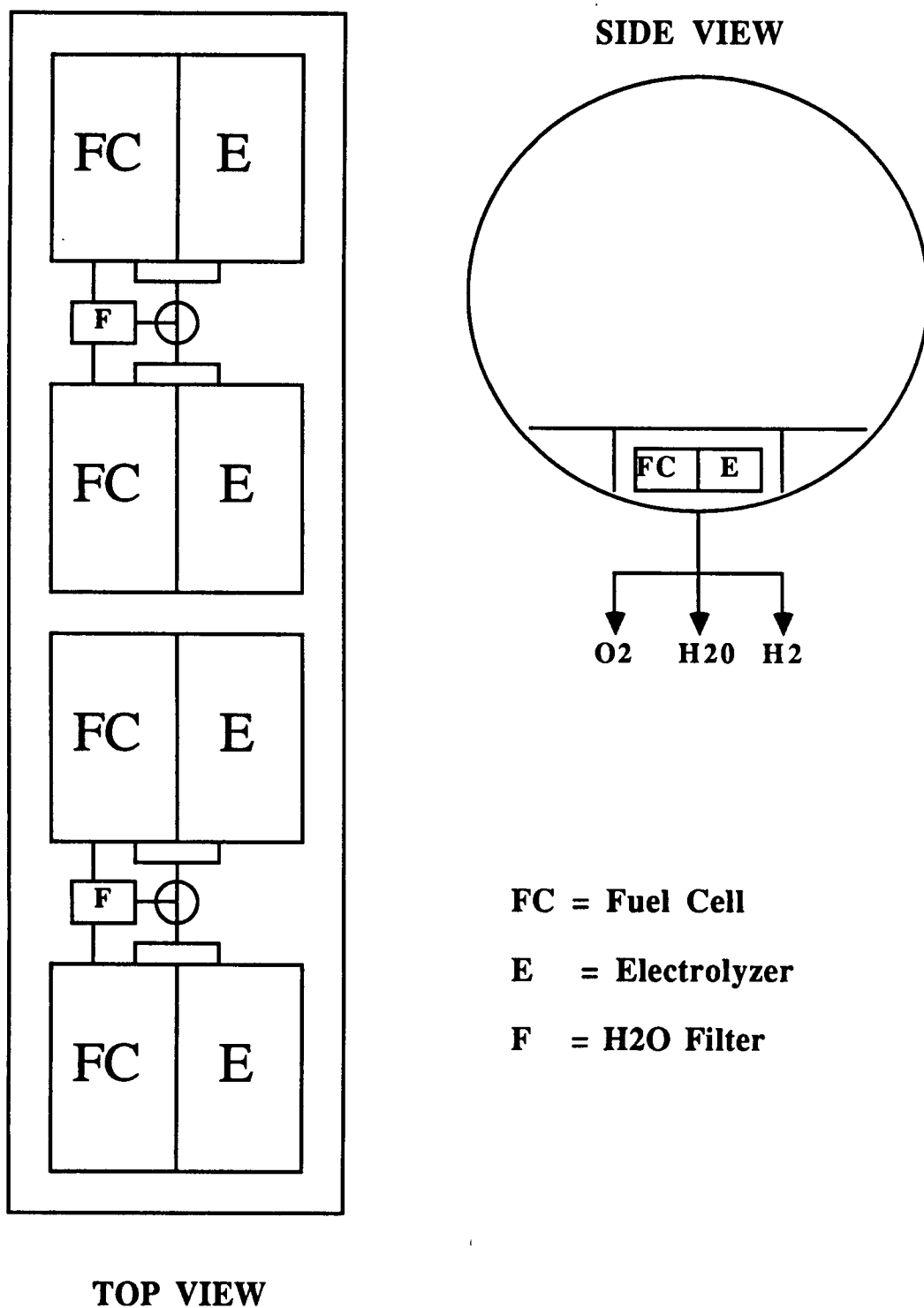
Source for data: Garow

TABLE 4.4.2-3
RFC MODULE ELECTRICAL CHARACTERISTICS

ELECTROLYZER		FUEL CELL	RFC MODULE
POWER (nom.) INPUT (kWe)			
GROSS	10.799	-	10.799
PARASITE	0.168	-	0.168
OUTPUT			
GROSS	-	10.170	10.170
PARASITE	-	0.165	0.165
VOLTAGE (v)	100 (dc)	100 (dc)	-
CELL VOLTAGE (v)	1.515	0.869	-
CURRENT DENSITY (AMPS/FT**2)	215	199	-
(mAMPS/CM**2)	231.2	214	-

Source for data: Garow

FIGURE 4.4.2-2
RFC POWER SYSTEM LAYOUT



by means of insulated pipes running through a single orifice in the center of the underside of the common module. The power system's operation is scalable with between one and four RFC units operating simultaneously. Table 4.4.2-4 shows two operations mode configurations for the power system. Nominally, two RFC units will operate together to generate 20 kWe for 168 hours. This configuration would require about 1337.1 kg of reactant fuel and would have a peak power output of about 60 kWe. Since extra propulsion fuel may be available, it may be possible to operate more than two RFC units for longer than one week. Table 4.4.2-4 shows if all four RFC units were used to generate 10 kWe each for one week, the required reactant mass would be about 2005.6 kg and the system would have a peak power output of about 120 kWe.

The RFC power supply / power storage system provides a relatively light weight, low volume, reasonably efficient (55% , Ref. Garow), scalable, immediately available power source. Additionally, the RFC power system has the capacity to store energy for future use as a backup power source. The power system makes use of the propulsion system storage tanks and any residual fuel they contain. The power system is integrated with the Lunar Shack's Environmental Control and Life Support Systems and provides the flexibility of conversion back and forth between stored water and stored oxygen.

4.5 Consumables and Waste Management Considerations

4.5.1 Requirements

The consumables and waste management requirements for a lunar base are similar to those for the Space Station. However there are some factors which create unique requirements for the lunar base and lunar shack. Some of these factors are gravity, structural differences on the habitat module, and specific lunar mission objectives. The lunar gravity will help simplify many of the housekeeping operations on the moon. The food packaging can take into account the gravity and eating on the moon will be more like eating on the Earth. Food packaging for zero gravity environments must ensure that no food can accidentally escape from the containers. This is not such a large concern for lunar meals because the lunar gravity will ensure that the food does not float away and ruin equipment. The shower and toilet facilities are other systems which will be designed to take into account the moon's gravity. Table 4.5.1-1 shows that 218.4 lbs of food are needed by a crew of eight for the period of a twenty-one day mission. This food will come in many different varieties and each type will have it's own storage and preparation requirements.

Many advances have been made in the food that can be taken into space. With the technology developed for Skylab and used in the Shuttle, meals on the moon will not be unlike meals on Earth. Food types such as rehydratable beverages, thermostabilized fruits, and irradiated meats will be available to the work crews on the moon (Ref. Klicka). Other types of food will be intermediate moisture foods and natural form foods.

Rehydratable items include both foods and beverages. To save weight, the water is removed from food for launch. The water is added back to the food just before it is eaten. The water can be hot or cold depending on the food. The water will be dispensed through automatic portion distributing faucets. Foods which can be rehydratable include soups, casseroles, and breakfast foods like cereals and eggs.

Thermostabilized foods are heat processed to destroy microorganisms and enzymes. Commercially available examples of thermostabilized foods are tuna or pudding in cans. The choices of thermostabilized food on the moon will include such food as sliced beef, chicken with barbecue sauce,

Table 4.5.1-1

	1 Person - 1 Day (lbs)	8 Persons - 1 Day (lbs)	8 Persons - 21 Days (lbs)
O₂	2	16	336
N₂	1.26	10.13	212.79
H₂O	4.7	37.6	789.6
Food	1.3	10.4	218.4
Solid Waste	.6	4.8	100.8

and ham. Most of the fruits will also be thermostabilized to ensure freshness.

Intermediate moisture food items are such things as dried fruits and dried beef. The water content in these foods is reduced to keep the foods moist while restricting the amount of water available for microbial growth. Nuts, cookies, and breads are natural form foods. They require no preparation and are ready for consumption. Meat is irradiated by exposure to ionizing radiation so that it is stable at ambient temperatures. Beef steak, smoked turkey, and corned beef are examples of irradiated foods.

The diet and menu plans are designed around a 3000 calorie day. There will be allowances for snacking and spoilage in the planning of the amount of necessary food for the trip.

4.5.2 Storage Space

This food will require locker and refrigeration space which is easily accessible for resupply and convenient to the gallery area for preparation of meals. Resupply of food lockers will be done from the inside of the ship. The lockers will be removable and collapsible. The empty lockers will be removed and the new supplies locker will be slipped in. Meals will be served in trays which contain slots for food containers and heating elements for warming of foods. After eating the meal, the containers are thrown away and the next meal is put into the tray. A typical three day menu is shown in Appendix D. The storage requirements for the consumable and waste management systems outlined above are summarized in Table 4.5.2-1. The solid garbage such as containers and food packaging will be compacted and stored in containers for return to Earth at resupply time. It is recommended that the dumping of wastes, solid or gaseous, into the lunar environment be minimized.

It will also be necessary to store and resupply consumable items other than food and water. There will be consumables such as pen and paper that the astronauts will use while on the moon. Lightbulbs, toothpaste, washing detergent, and other personal hygiene articles will be stored and resupplied in quantities necessary to ensure their availability throughout the mission.

Table 4.5.2-1

Water Tanks	
potable	
50 gallons	962.46 cubic ft
washing	
30 gallons	577.20 cubic ft
Nitrogen	212.79 lbs
Oxygen	336 lbs
Food	
lockers	44 cubic ft
refridgerated	10 cubic ft

4.5.3 Water/Waste Management

There are two alternative designs to consider for the water management system. The first is a space station type system which includes three water reclamation subsystems; one for drinking water, one for hygiene water, and one for wash water. This system concept is closed except for resupply of water filters, post-treatment chemicals and N_2 .

It is assumed in this system that the food contain enough water to maintain the water supplies of the system. Potable water is derived from humidity condensate. This includes the water formed during CO_2 removal and CO_2 reduction. These are the least contaminated sources of water in this type of system. The water would require some taste enhancers to improve the quality.

The water in the hygiene subsystem would be used for showering, washing hands, and generating oxygen. This water is reclaimed from urine and dirty shower/handwash water by a distillation process. The wash water used for laundry and dishes is the least clean of the processed waters. This water is reclaimed from fuel cells and overflow of the other water loops in the system. A filtering system will be used to process the water at minimum energy expense. By dividing the water into three subsystems this water management system saves energy. Since all the water does not need to be potable, lower energy methods of filtering and processing can be used to maintain water supplies.

The second design to consider is built around a super critical water oxidation system (SCWOS). In a SCWOS the physics and chemistry of molecules above their supercritical pressure and temperature create conditions which allow hydrocarbons to mix freely (Ref. Modar). When water is above its supercritical pressure (25.3 MN/m^2 (250 atm)) and temperature (627.6 K (670 F)) instantaneous combustion occurs when there is enough oxygen in the medium. Combustion of organic compounds yields CO_2 , H_2O , and N_2 . Inorganic ions will form salts which can be filtered out with a solids filter. The temperature can be generated but this would take as much energy as would be saved using the SCWOS. The heat can be obtained from the heat released when H_2 and O_2 are mixed. The atmosphere supplies for the lunar lander will be stored cryogenically as liquids. When these liquids are mixed, heat is a by product of their combination. The H_2 and O_2 are fed into the SCWOS along with the dirty

water and their reaction heat is used to maintain the temperature necessary for the combustion process. A nitrogen-containing solid and post-treatment chemicals are the only required resupply for this system. The nitrogen-containing solid is added to the normal wastes fed to the SCWOS such as dirty water, urine, feces, and garbage. This N_2 which is produced by the SCWOS can be used to augment the cryogenic supplies of N_2 used in for the cabin atmosphere.

This type of system would require only two reclamation subsystems; the hygiene loop, and the potable water loop. Hygiene water will be used for handwashing, showering, laundry, or dishwashing. Dirty hygiene water and humidity condensate will be cleaned by a filtering process and returned to the hygiene water storage after post-treatment. Potable water will come from the CO_2 reduction system and the SCWOS. Chemicals must be added to the potable water to enhance the taste and restrict the growth of bacteria in the water.

There are many aspects of the SCWOS water management system that make it better than the space station type system (SS). The SS type system is more complicated with three separate water loops compared to two loops in the SCWOS. Another important consideration is the need for liquid nitrogen in the SS type system. The use of a nitrogen-containing substance in the SCWOS is the alternative to liquid nitrogen. This substance can be a solid, powder, or a nitrogen rich liquid, which is reduced to N_2 by the SCWOS process. The amount of potable water produced is another reason that the SCWOS is a good system. The SS type system produces half as much water as the SCWOS. With the SCWOS there is a possibility that enough potable water is produced to allow potable water showers and laundry cycles.

These reasons support the development of a SCWOS water management system over the space station type system. Two water tanks will be needed to keep the potable and hygiene supplies separate. The nitrogen supply will be stored as either cryogenic or solid substance. This space will be determined later depending on the final system picked. There will be liquid oxygen supplies in addition to the oxygen supplied from electrolysis of water supplies.

4.6 Communications

A communications net must be provided for the shack's missions. This net must provide communications between the shack, Moonport, Earth, and any crew members engaged in EVA. As a secondary concern, this net can provide a number of navigational aids, both in landing the crew transport and in EVA out of sight of the shack. Table 4.6-1 gives an outline of the communication systems.

The comm net required consists of antennae on the Moonport and the shack, a portable ground station with the EVA crew, and a severely modified TDRS (Tracking and Data Relay Satellite) group. All antennae involved will be gimballed, locking on to their targets through the use of the wide S-band and transmitting on the more precise Ku-band (15,250 to 17,250 MHz). (ref: Space Shuttle Transportation System, March 1982; Rockwell International) The use of the S-band lock-on with TDRS could be used in locating EVA crews in the same manner as a Global Positioning Satellite.

The comm net's primary function is to relay data. To this end, there are three components: the Uplink (from Moonport/Earth); the Downlink (to Moonport/Earth); and the Audio Distribution System (ADS).

The uplink consists mainly of three types of data: 1) ground commands that are sent from mission control to the shack's on board computers; 2) voice transmission that are sent to ADS; and 3) video from Moonport/Earth. The downlink is responsible for: 1) voice from ADS to Moonport/Earth; 2) operational instrumentation telemetry; and 3) video returned to Moonport/Earth.

Lastly, the Audio Distribution System co-ordinates crew voice communication by headset and intercom, and distributes caution and warning signals.

Table 4.6-1**COMMUNICATIONS SYSTEM**

COMMNET * TDRSS (MODIFIED TO TRANSMIT TO MOON)
 * NETWORK LINKS GROUND SUPPORT,
 MOONPORT, SHACK, CREW ON EVA

ANTENNAE * OPERATES ON KU BAND
 (15,250 MHz to 17,250 MHz)

NETWORK SIGNAL PROCESSOR (NSP)**UPLINK:**

- * GROUND COMMANDS SENT TO ON BOARD COMPUTERS
- * VOICE SENT TO AUDIO DISTRIBUTION SYSTEM (ADS).
- * VIDEO

DOWNLINK:

- * VOICE FROM ADS
- * OPERATIONAL INSTRUMENTATION TELEMETRY
- * VIDEO

AUDIO DISTRIBUTION SYSTEM

- * CREW VOICE COMMUNICATION BY HEADSET AND INTERCOM
- * DISTRIBUTES CAUTION AND WARNING SIGNALS

4.7 Spacecraft Interior

Since the lunar shack is designed to sustain life for an extended period, considerations on interior design are as important as other major parameters such as weight or radiation protection. In this vehicle some of the criteria for design were :

LIVING SPACE
STORAGE SPACE
PSYCHOLOGY EFFECTS
SPACE UTILIZATION
TOTAL MASS

Since S.E.C.'s final design is based around the space station common module, a quick interior description is presented. The module itself is mainly a cylinder with interior dimensions of 11.79 meters long and 4.22 meters diameter. There are end cones but these are small in comparison to the rest of the craft so they will not be considered. The adapted common module (Ref: Guerra), has a rectangular living area 3.44 meters wide and 2.44 meters high. Figure 4.7-1 shows a cross section of this module with a representative figure 6 feet tall to show spacial relationship. For this basic module the areas above and below the living space are undefined and will be used for storage.

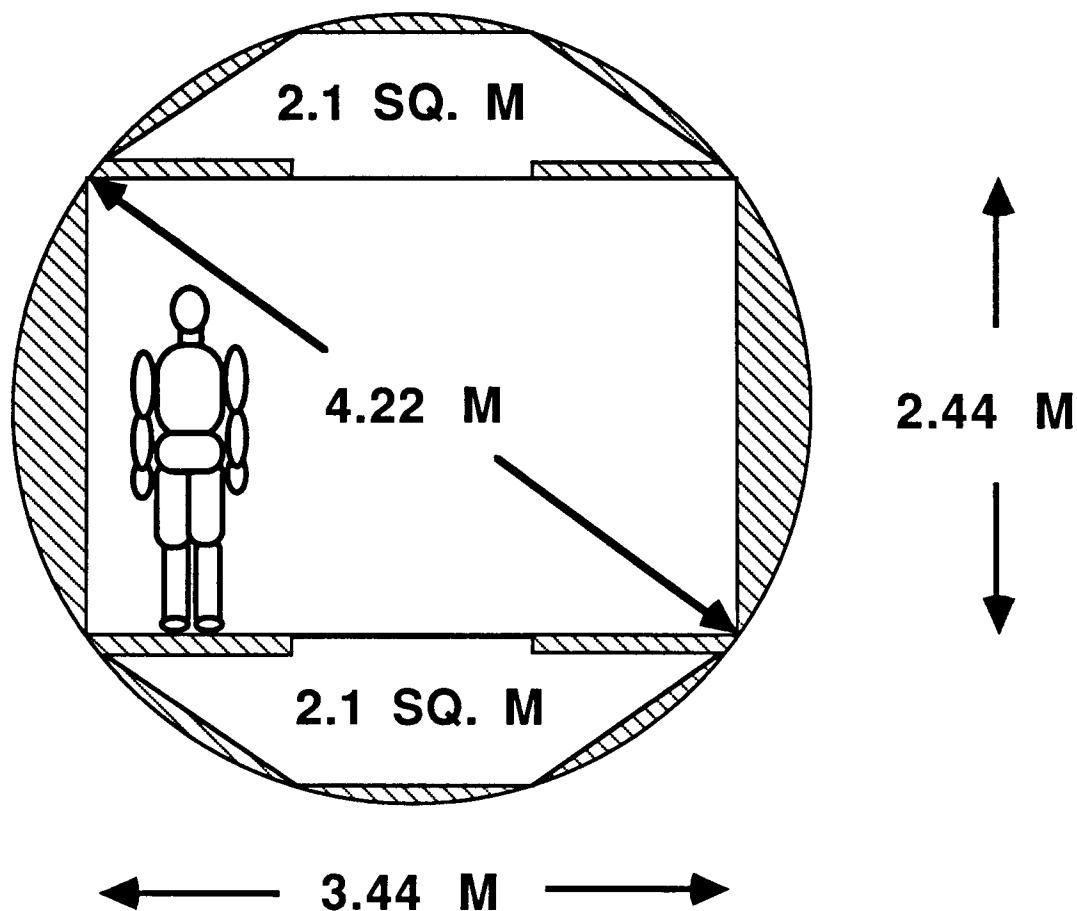
Figure 4.7-2 shows the overall interior layout of the three major sections of the craft, the living module and the two airlock modules. The living module is divided into three portions, the galley, the bedroom / command and control, and the health maintainence area.

Figure 4.7-3 shows the top and cross-sectional views of the galley. Under the floor are the main consumables storage (2 cubic meters), potable water storage (283 Liters), and the four fuel cells. The fuel cells are linked to the H₂, O₂, and non-potable water storage tanks, in the lower stage, directly through the skin of the module. In the ceiling of the galley is the ECLSS equipment.

Figure 4.7-4 shows side views of the galley. Although major food storage will be in the floor, a small wall refrigerator will be incorporated into the design to lower dust contamination in the main refrigerator and increase ease of use. In the galley, along with the food preparation and

LIVING SPACE - 99 CU. M

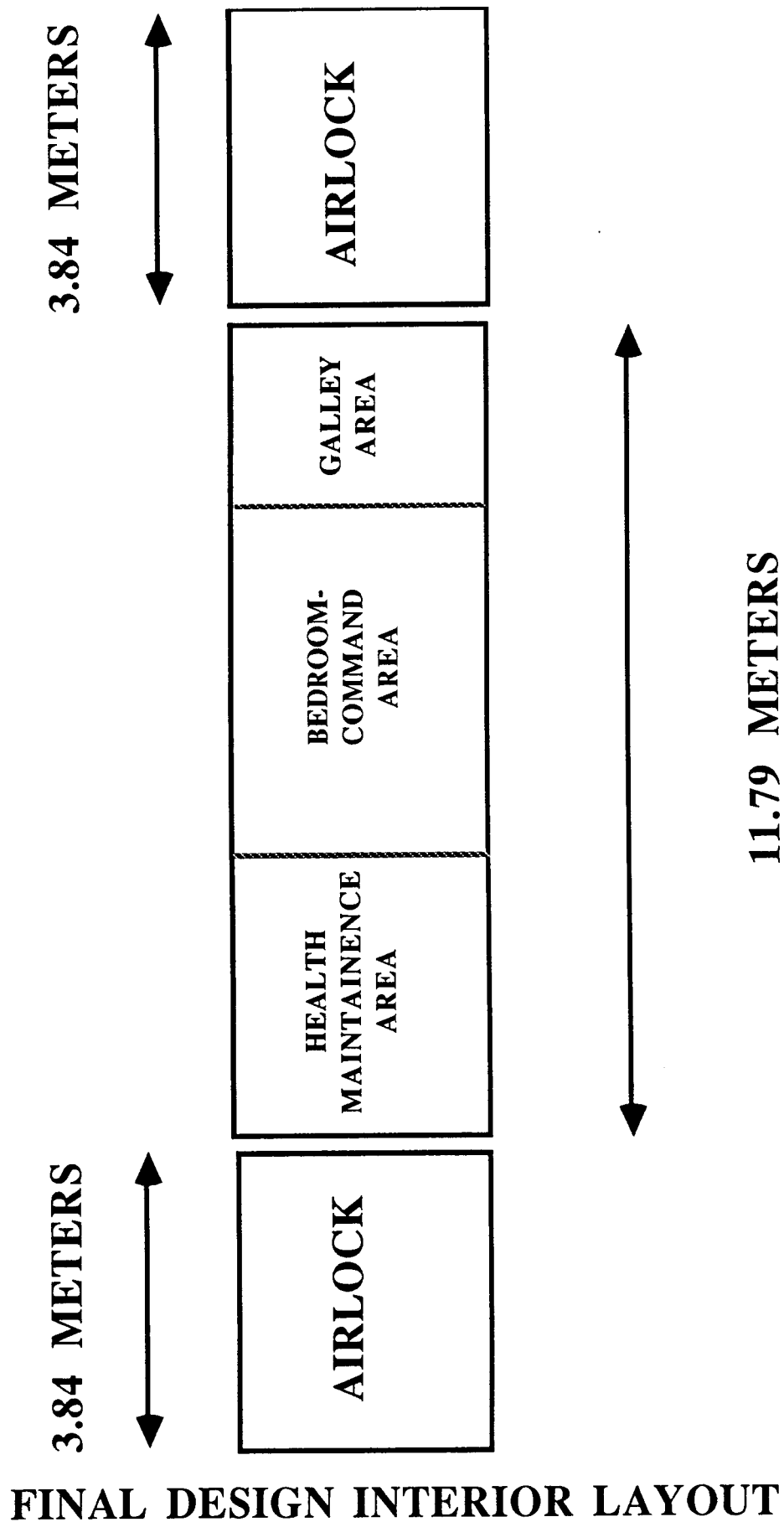
STORAGE SPACE - 50 CU. M



ADAPTED SPACE STATION COMMON MODULE

INTERIOR LIVING SPACE

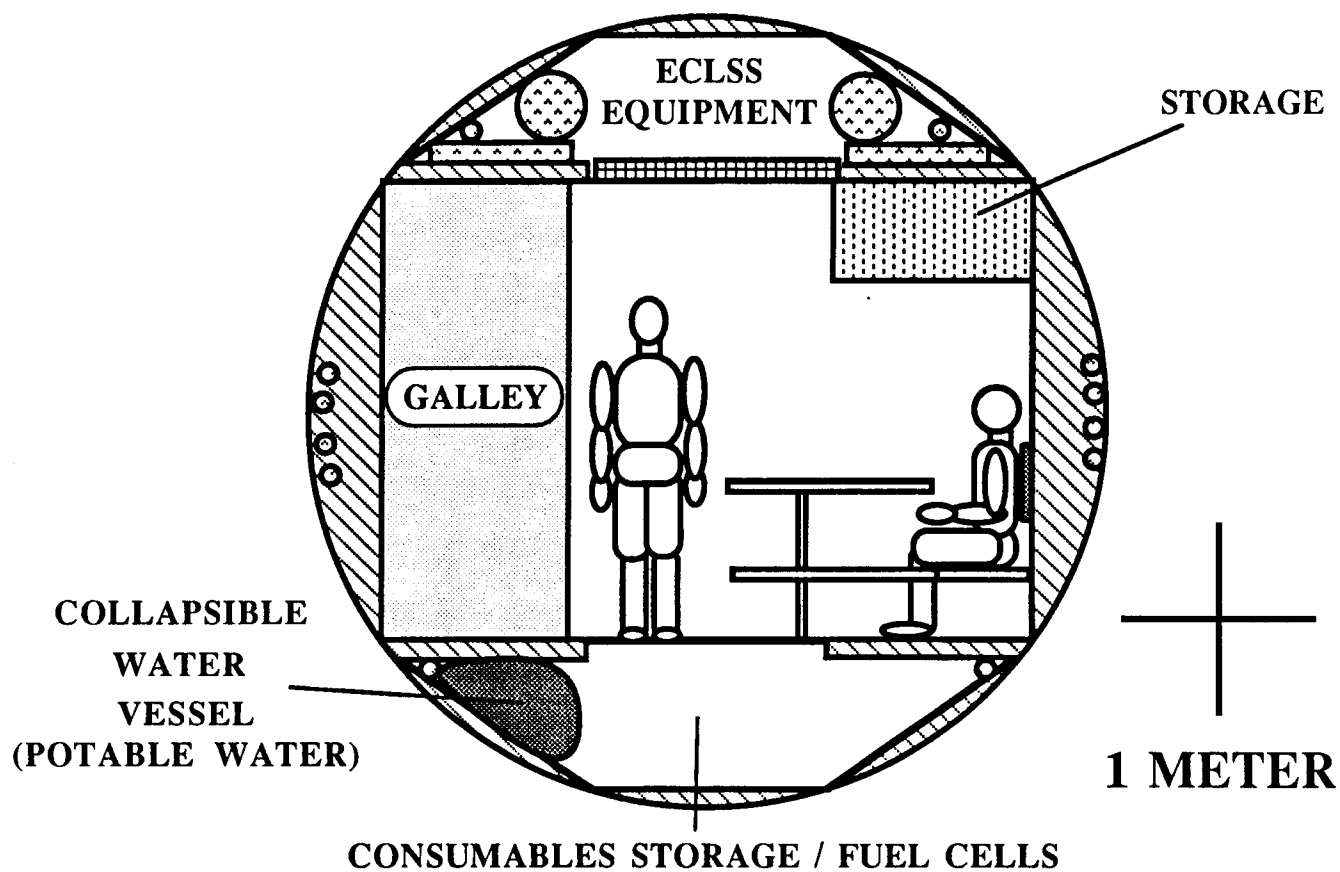
Figure 4.7-1



FINAL DESIGN INTERIOR LAYOUT

Figure 4.7-2

CROSS SECTION / GALLEY AREA



2.87 METERS

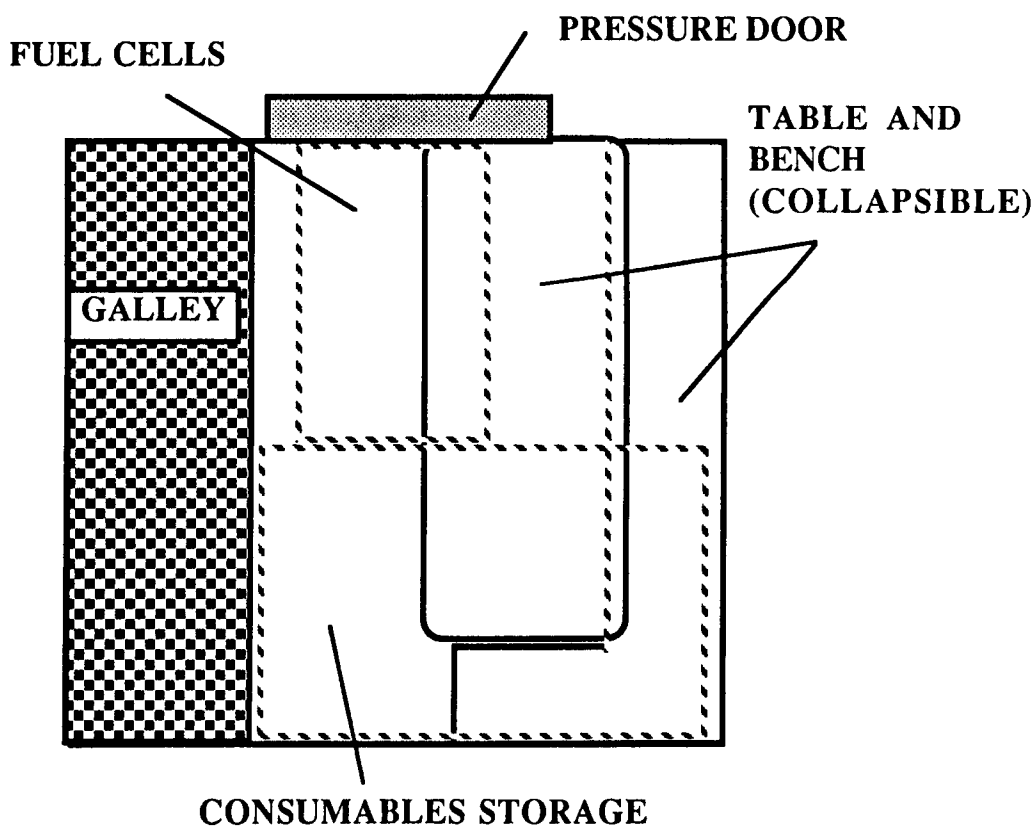
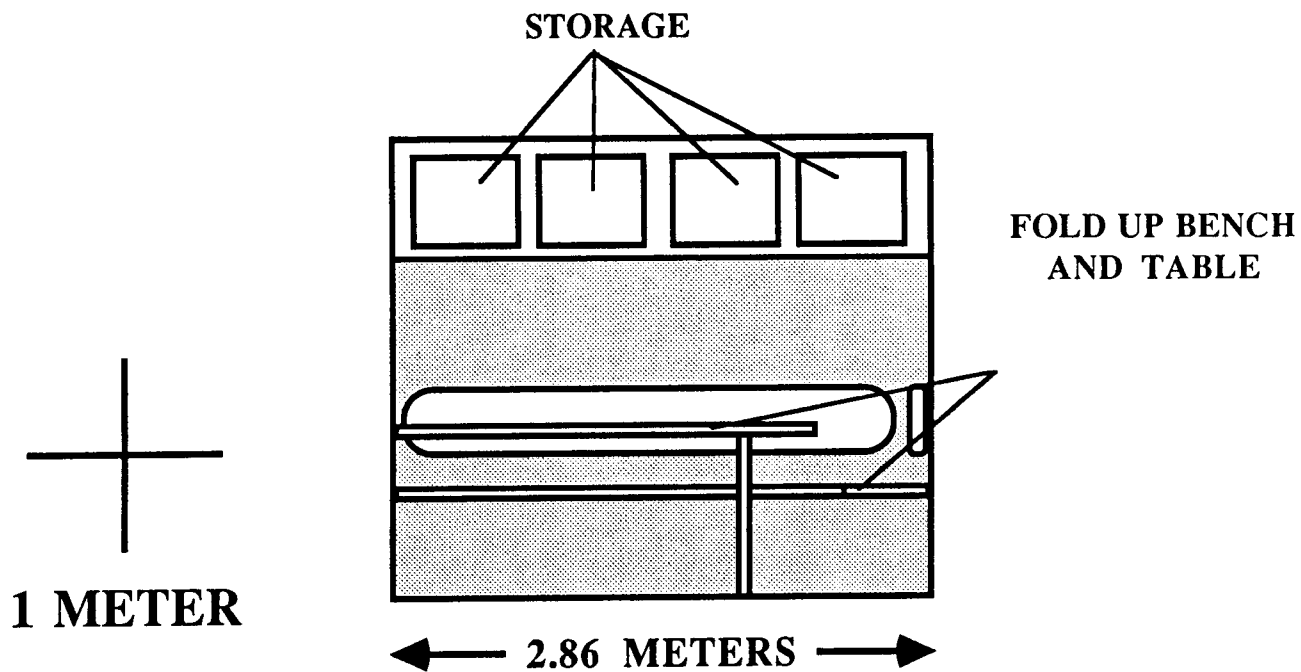
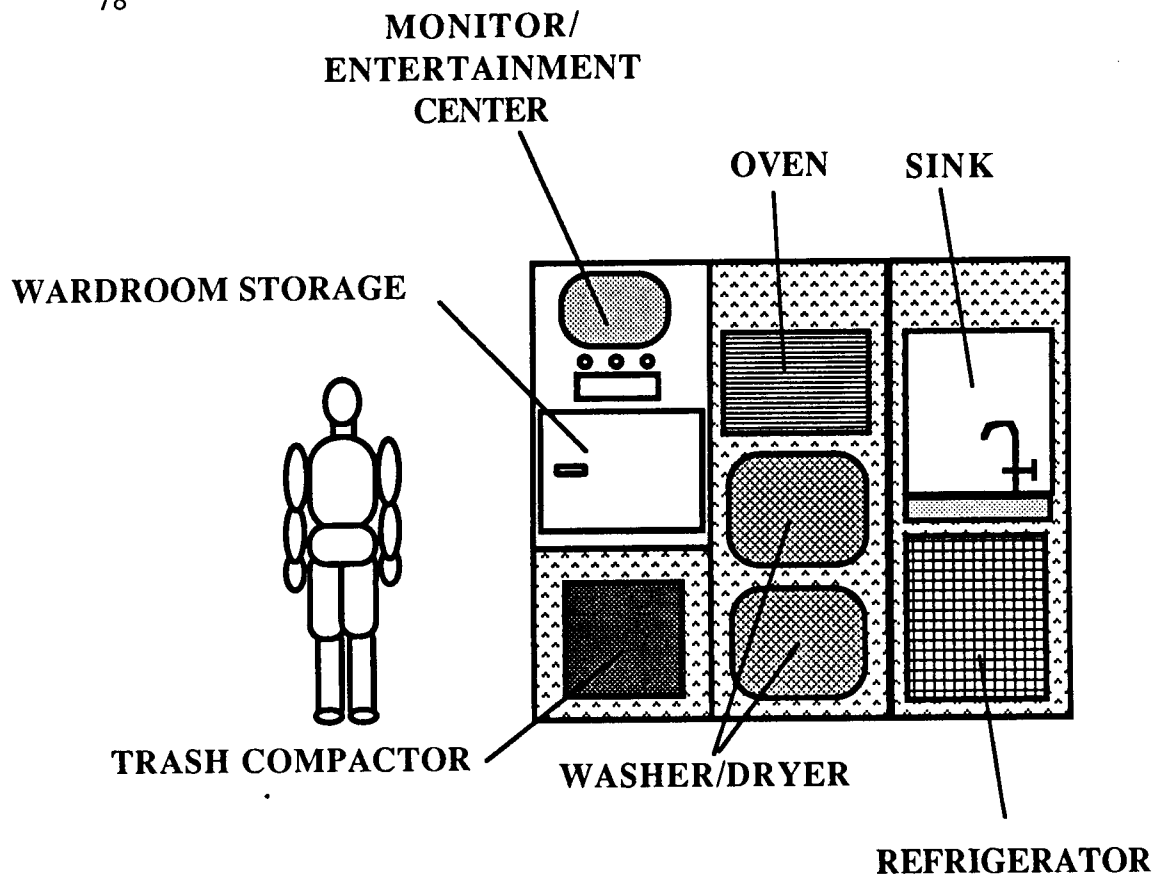


Figure 4.7-3



GALLEY AREA SIDE VIEWS

Figure 4.7-4

clothes cleaning equipment, will be an entertainment center for the recreation of the crew.

The bedroom / command and control top view is shown in figure 4.7-5. There are eight fixed beds , a shower, a toilet, a command area with six control screens and communication equipment, and the waste management system. The command displays are multipurpose, low power, tubeless, flat screen displays. These can be interfaced with any video type information, including, but not limited to, outside camera monitors, system monitoring, or communications. Because of the nature of these screens they are reliable, safe from implosion, easy to replace, and can be further incorporated into the vehicle's entertainment system. At this point the utility of having command and control in the sleeping area should be noted. This aids in the reaction time in case of trouble during resting hours.

Figure 4.7-6 shows the side views, and figure 4.7-7 shows a cross-section of, the bedroom area with some ideas of how the storage space is utilized. In the walls can be seen conduits for power, water, and communications. The ceiling area incorporates air ducts, lighting, pressure vessel storage, and electronic equipment storage. In the floor are the waste management system (between the shower and toilet), the emergency O₂ and LiOH supplies, and crew personal storage.

Figure 4.7-8 shows a general indication of the health maintenance facility size and is based upon the adapted common module (Ref: Guerra) equipment sizing . This design will not incorporate an X-ray machine or blood analysis unit. Any crew member requiring this type of treatment will be assumed incapacitated as far as the mission is concerned and will be evacuated.

For the airlocks a general design has been incorporated using a University of Texas at Austin study (Ref: Foster T.S. et al). They include space for two individuals and their equipment. These airlocks will be removable so the modules that contain them can be converted into an interconnection nodes for interface with the bootstrap base if desired. Figure 4.7-9 shows top and cross-sectional views of the airlock module and staging area proposed. This design uses the common module cylinder foreshortened and includes storage for four 'hard' EVA suits (hard meaning full pressure with external shell), four conformable life support back packs, and emergency soft suit storage. In the floor of the module is the

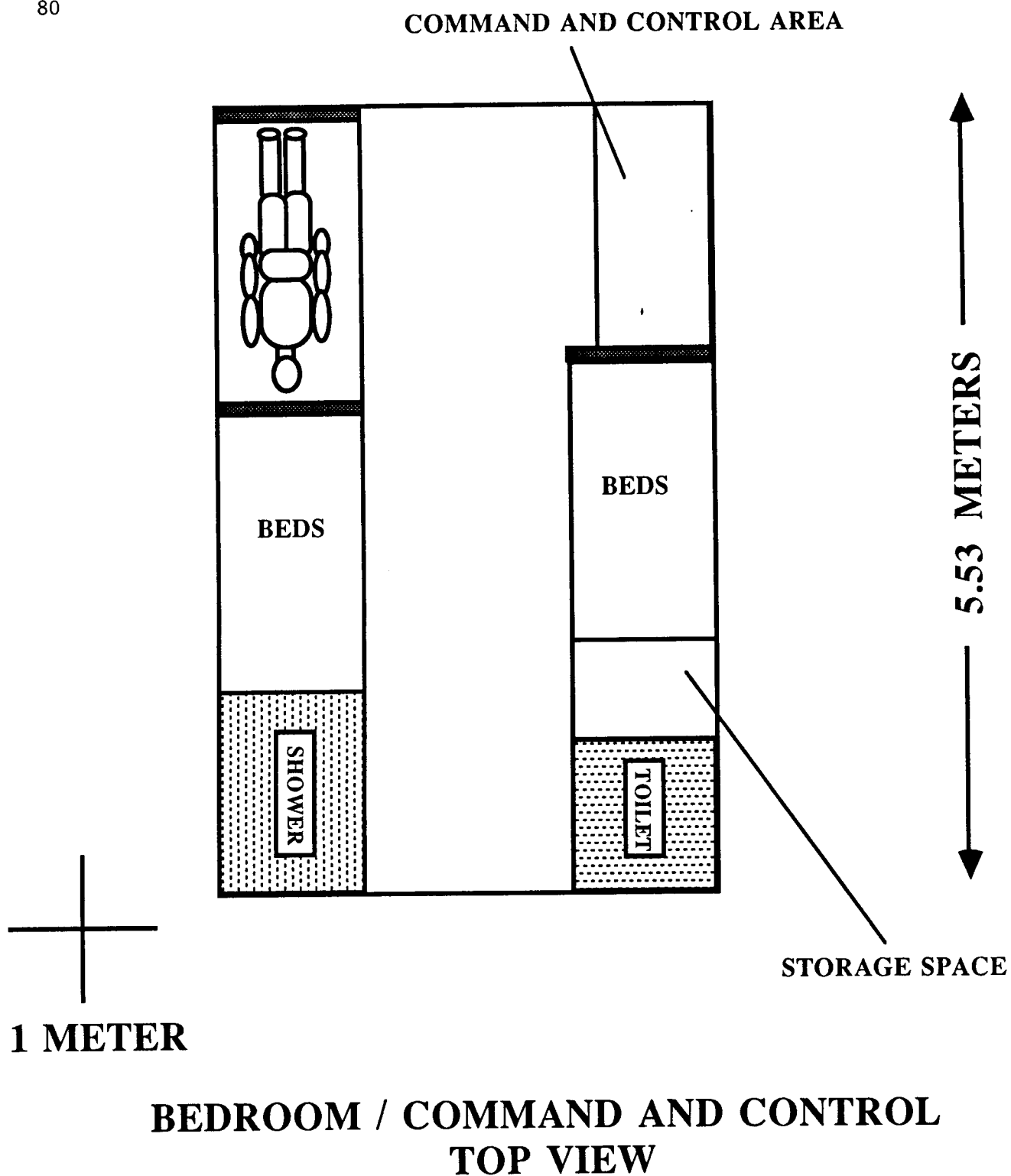
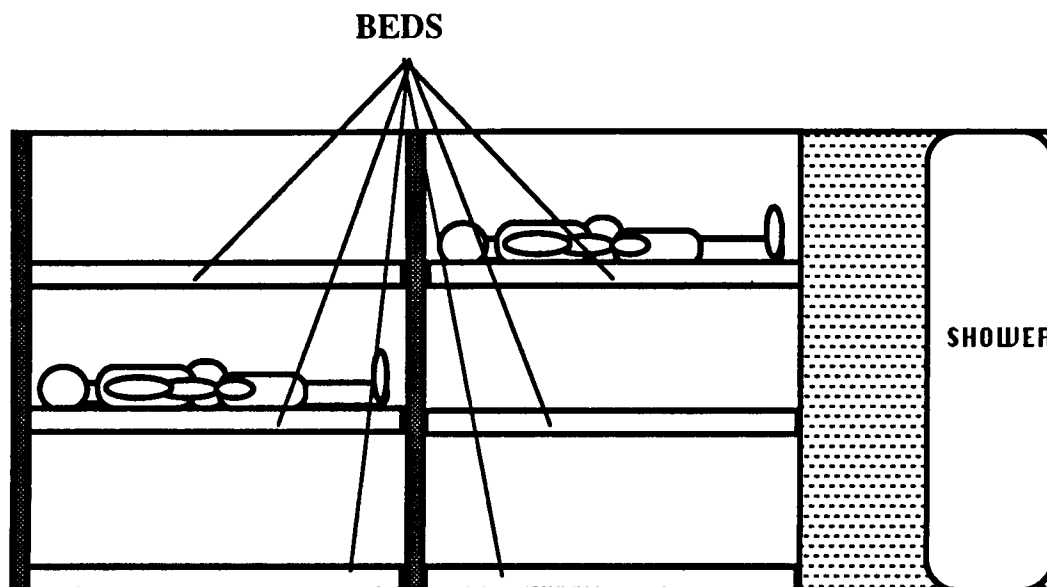
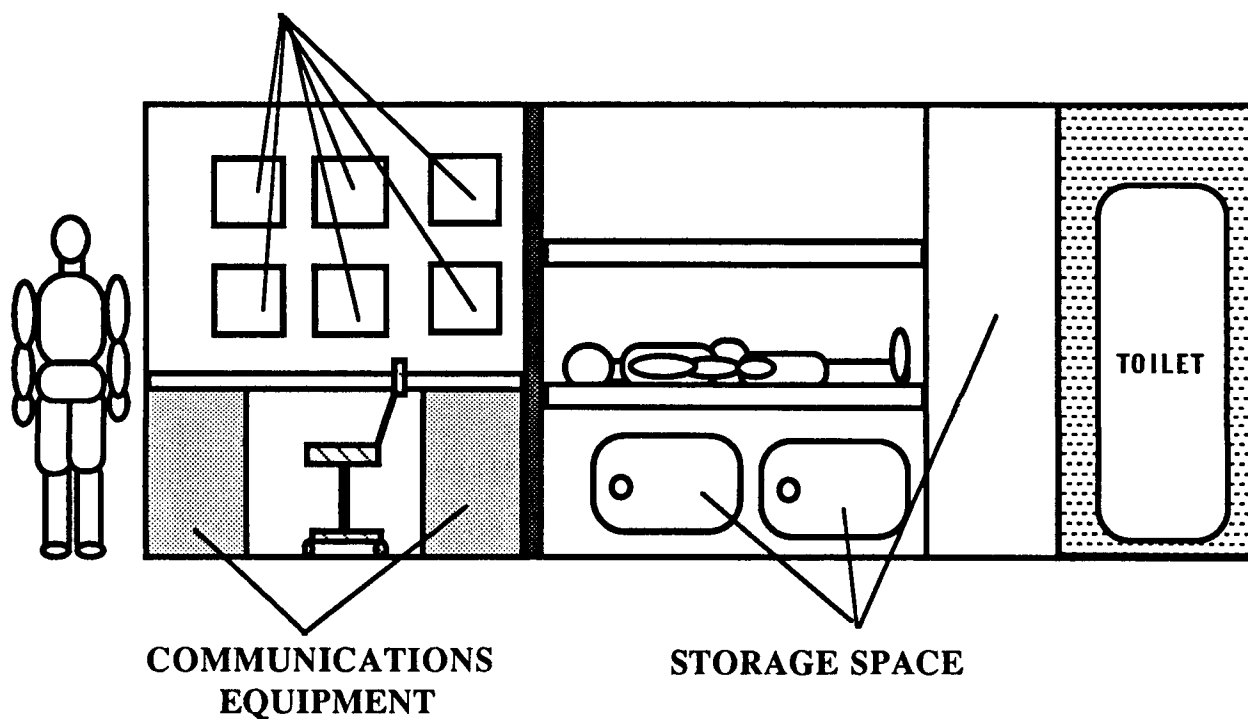


Figure 4.7-5



← 5.53 METERS →

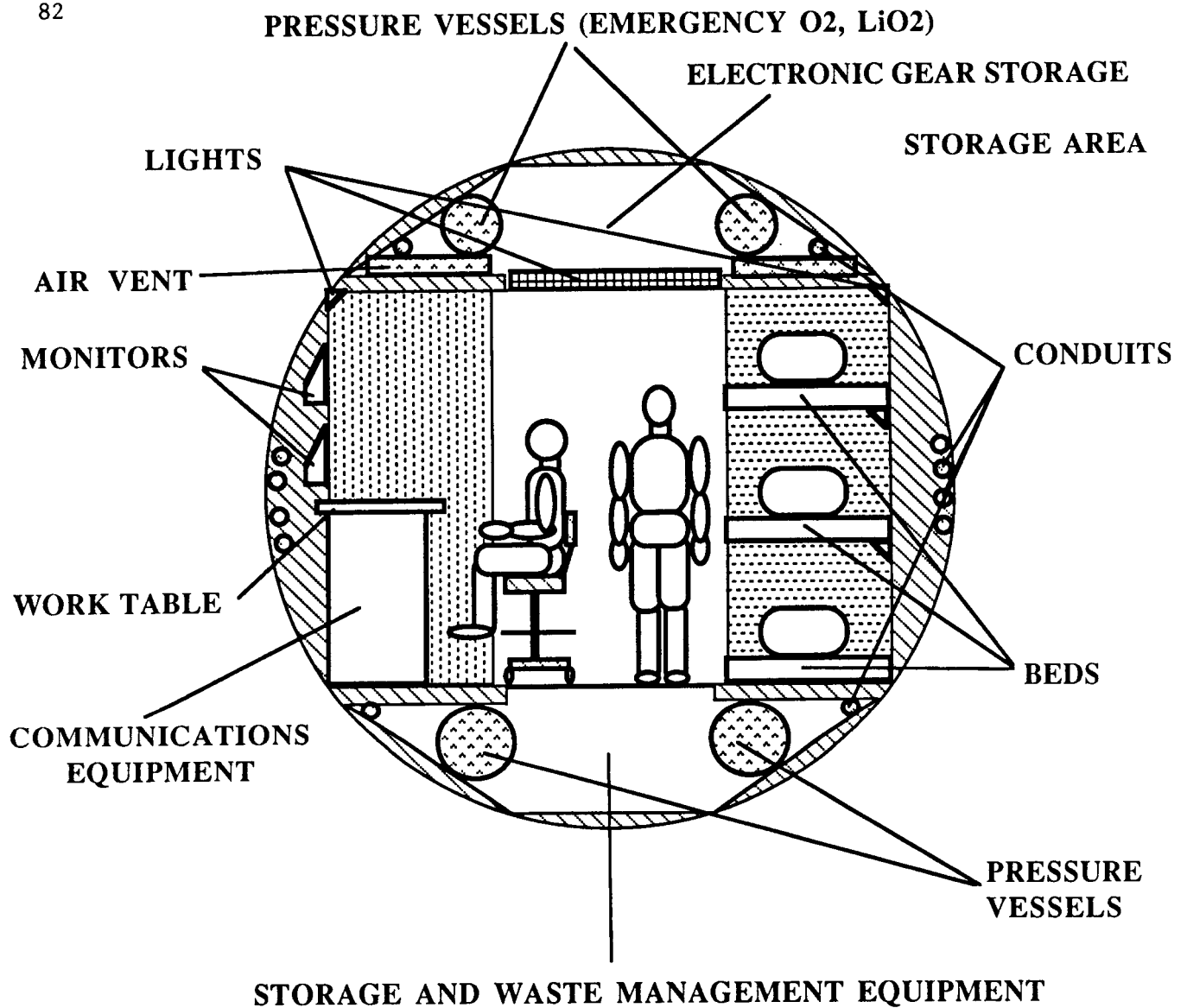
CONTROL MONITORS



**BEDROOM / COMMAND AND CONTROL
SIDE VIEWS**

Figure 4.7-6

1 METER



CROSS SECTION / BEDROOM

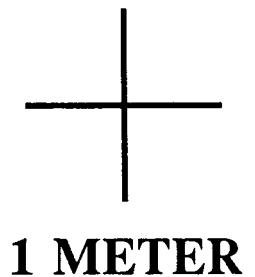
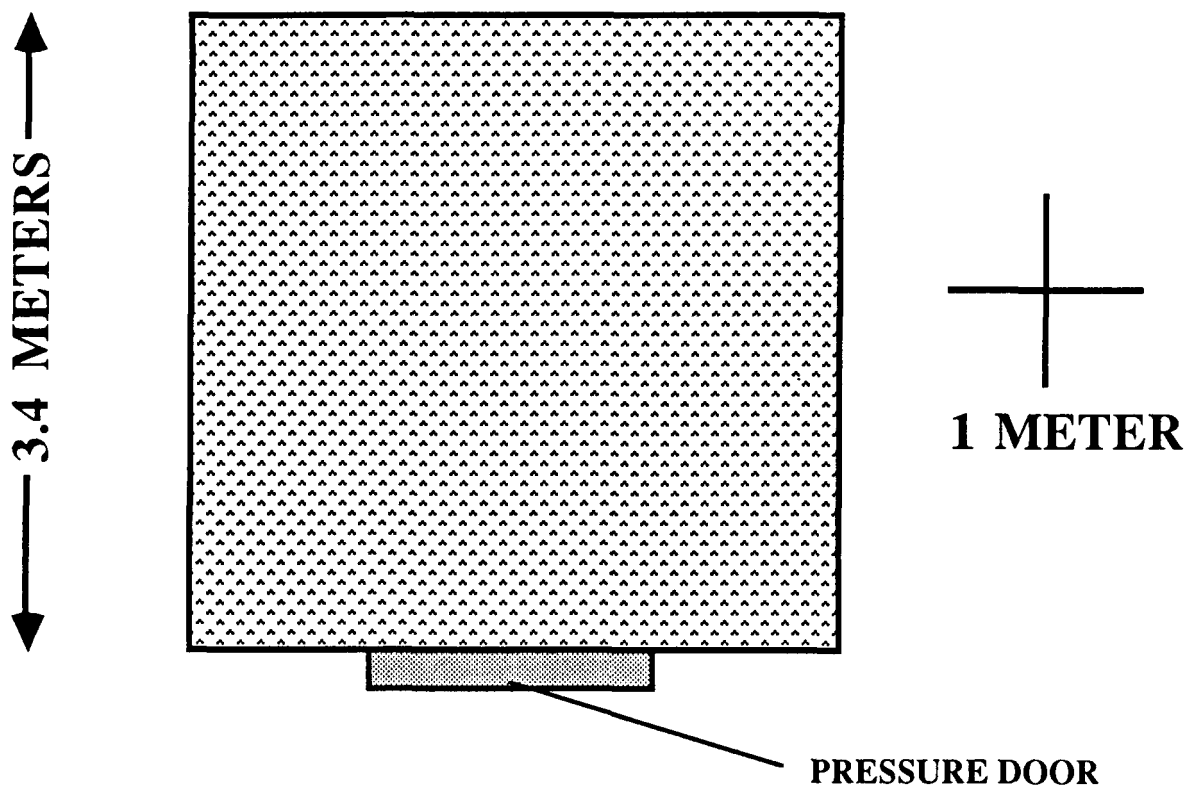


Figure 4.7-7



**HEALTH MAINTAINENCE AREA
TOP VIEW**

Figure 4.7-8

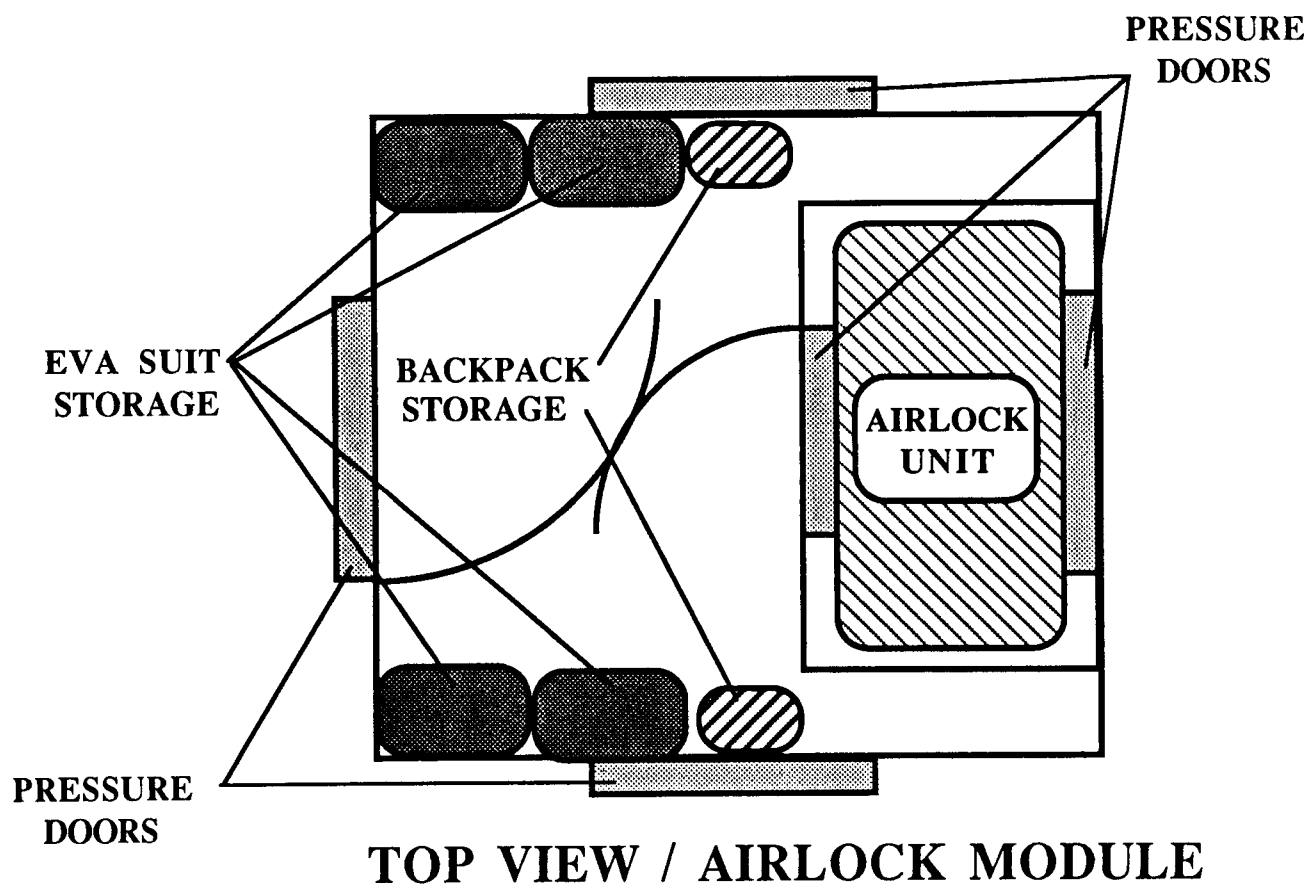
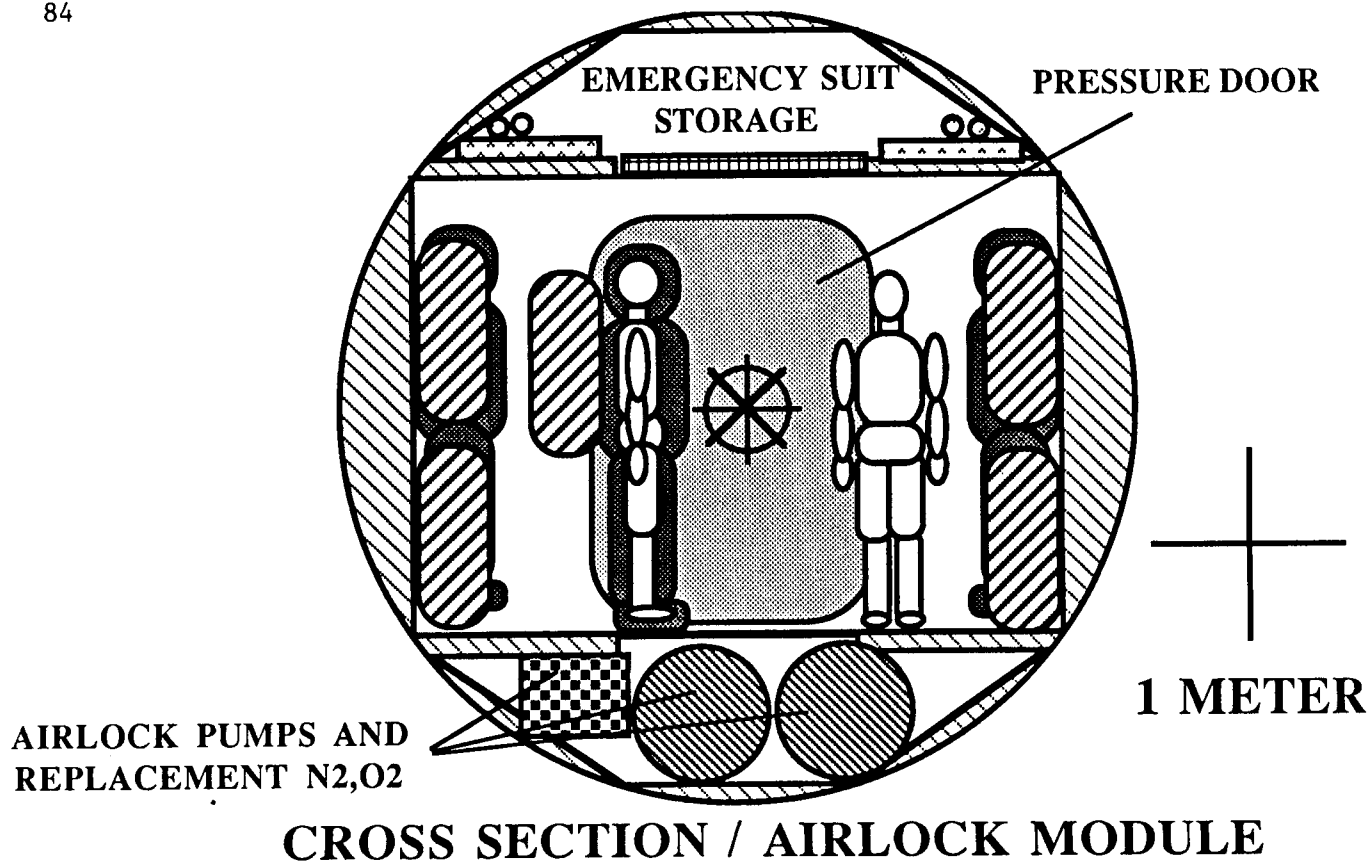


Figure 4.7-9

replacement N2 and O2 supplies (for compensation of airlock losses) and the airlock pump.

At this point it is important to note the problems inherent with airlocks and what methods could be used to overcome them. First is the dust problem on the moon. Dust can and will get on the airlock seals and eventually cause air leaks. To help limit the effects of the dust two things can be done. The dust on the suits can be brushed off of the EVA suits while the crew members are waiting for the pumping cycle to complete on ingress. If the airlock is designed with a grating the dust can be cleaned out of the grating periodically and thus keep a major portion of the dust out of the craft. The portion of the dust that is left on the suits, and on the inner airlock seal, can be wiped off with a damp towel. The major problem with dust contamination exists on the outside airlock seal. Again, this can be wiped with a towel that is impregnated with some substance (a problem in itself) to help remove the dust.

The second problem with airlocks occurs in emergency situations. Airlocks are, by design, minimized for volume, in this example, enough for two crew members and hardware, and if something such as a radiation event or medical emergency where a member cannot be placed in the airlock vertically occurs a limit is placed upon the speed of ingress. SEC designs solve this problem by using the staging areas as emergency airlocks. A typical procedure would be:

The interconnecting door to the main vehicle would be closed and sealed (this would be done by members still in the vehicle or by the last member out of the vehicle), both airlock doors would be opened and anyone needing to ingress would do so into the staging area. The outer airlock door would be closed and the pressure between the airlock area and the main vehicle would be equalized. This would drop the interior pressure and the vehicle system should have a system that could account for this so the crew could concentrate on the trouble at hand. A note: dropping the pressure will cause water in the air to condense and form a thick fog. Again, this must be dealt with by both the crew and the vehicle systems.

Since all of the equipment required for the mission has, as yet, not been defined, a completely detailed design could not be developed. This is a general interior layout and has only allowed for a reasonable amount of space for model facilities and is used to indicate that there is enough room in the common module to support eight individuals on the moon for the three week mission length in this report.

For the final design, facilities should be as simple as possible for increased reliability and ease of repair and yet still supply all of the needed solutions to such common problems as personal hygiene, supply storage, personal space, health maintenance and ease of resupply.

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6.0 Appendices

Appendix A.

Transfer from Moonport to the Lunar Surface

Based on LOCO's Bootstrap Lunar Base and SPS's Transportation Network to the Moon, the Moonport orbit is assumed to have the properties:

- (a) inclination of 179.5 degrees,
- (b) eccentricity of 0.0,
- and (c) an altitude of 100 km;

and the moon's properties are known to be:

- (a) 1738 km radius,
- and (b) $4902.87 \text{ km}^3/\text{sec}^2$.

The transfer orbit has:

- (a) apogee radius of 1838 km, and
- (b) perigee radius of 1738 km.

For these values, the semi-major axis is 1788 km.

For the Moonport orbit, the velocity,

$$v_1 = (\mu / \text{apogee})^{1/2} = 1.633 \text{ km/sec.}$$

The velocity of the transfer orbit at apogee is given by,

$$v_a = (2 * \mu (1/r_a - 1/2a))^{1/2} = 1.610 \text{ km/sec.}$$

The difference between the two velocities (and the first delta v) is

$$\text{delta } v_1 = -23 \text{ m/sec.}$$

At the surface, the velocity of the transfer orbit is:

$$v_p = r_a * v_a / r_p = 1.703 \text{ km/sec.}$$

The velocity of the moon's surface at its equator due to rotation is $v_m=4.6 \text{ m/sec}$, and since the transfer orbit is retrograde, the delta v for landing is:

$$\text{delta } v_2 = - (v_p + v_m) = - 1707.6 \text{ m/sec.}$$

The magnitude of the total delta v for the transfer to the surface is:

$$\| \text{delta } v \text{ tot} \| = 1730.6 \text{ m/sec.}$$

Appendix B

Burnout Mass Calculations

19,000 kg	mass of loaded common module
<u>2 x 3000 kg</u>	loaded connecting node (used as estimate for for airlock)
25,000 kg	
<u>+ 91.2%</u>	ratio of loaded lower stage to habitation mod. (Ref. Baker)
47,794 kg	
<u>+ 15%</u>	factor of safety
54,963 kg	Burnout mass for vehicle

These calculations do not include the mass of the radiation shield wall and collar. An estimate of these masses was not available at the time these calculations were needed.

Appendix C

Fuel Tank Sizing

From the fuel calculations, the necessary propellant mass is:

8806 kg H₂
52837 kg O₂

O2 Tanks	Density of liquid oxygen	$\rho_{O2} = 1149 \text{ kg/m}^3$
	Volume of O2 tanks	$V_{O2} = m/\rho_{O2}$
		$= 45.985 \text{ m}^3$

The width of the center portion of the lower stage depends on the diameter of a single O2 tank:

$$V_{O_2} = 0.25\pi d_{O_2}^2 L$$

where:

- d_{O_2} = diameter of an O₂ tank (m),
- L = length of central portion of lower stage (m).

Solving for d_{O_2} :

$$\begin{aligned} d_{O_2} &= (4V_{O_2}/\pi L)^{1/2} \\ &= (4 \cdot 22.993 / \pi \cdot 14)^{1/2} \\ &= 1.446 \text{ m} \end{aligned}$$

Rounding this up to 1.5 m for lower stage dimensions allows room in the lower stage for tanks walls and insulation.

H2 Tanks	Density of liquid hydrogen	$\rho_{H2} = 70 \text{ kg/m}^3$
	Volume of H2 tanks	$V_{H2} = m/\rho_{H2}$ $= 125.8 \text{ m}^3$

The space for the H₂ tanks are determined by the length of the central portion of the lower stage:

$$\frac{\underline{L} - w_E}{2} = 6.5 \text{ m} \Rightarrow d_{H_2} = 6.5 \text{ m}$$

where:

- w_E = width of the engine (m)
- L = length of central portion of lower stage (m)
- d_{H_2} = diameter of an H₂ tank (m).

$$V_{H2} = 0.25\pi d_{H2}^2 h$$

C-2

where: h = height of an H₂ tank (m).

Solving for h :

$$\begin{aligned} h &= 4V_{O_2}/\pi d_{H_2}^2 \\ &= 4*62.9/\pi*6.5^2 \\ &= 1.896 \text{ m} \end{aligned}$$

Similar to the O₂ tanks, rounding this up to 2.0 m for lower stage dimensions allows room in the lower stage for tank walls and insulation.

Appendix D

Sample Menu

Meal	Day 1	Day 2	Day 3
A	Scrambled Eggs Sausage Patties Strawberries Bread Jam Orange Juice Coffee	Cornflakes Chocolate Instant Breakfast Grape Drink Coffee	Scrambled Eggs Sausage Biscuit Cocoa Coffee
B	Chicken and Gravy Asparagus Peaches Biscuit Cocoa Lemonade	Cream of Potato Soup Chicken and Rice Pre-Buttered Roll Peaches Lemonade	Cream of Potato Soup Pork & Scalloped Potatoes Green Beans with Cheese Sauce Pears Grape Drink
C	Veal & Barbecue Sauce Mashed Potatoes Green Beans with Cheese Sauce Peach Ambrosia with Pecans Grapefruit Juice	Filet Mignon German Potato Salad Pears Biscuit Cocoa Grape Drink	Lobster Newberg Mashed Potatoes Asparagus Vanilla Wafers Vanilla Ice Cream Lemonade Snacks: Dried Apricots Coffee x 2

APPENDIX E

- A. SKIN - The average amount of radiation a human's skin would receive if unexposed on the lunar surface during years of low solar activity is 50 rem/yr (Guerra, L., 1987).

1.) 30-days on Moon 50 rem/yr = 0.137 rem/day

$$\text{dose} = (0.137 \text{ rem/day})(30 \text{ days}) = 4.110 \text{ rem}$$

2.) Transit time 18 days

$$\text{dose} = (0.137 \text{ rem/day})(18 \text{ days}) = 2.466 \text{ rem}$$

3.) Total

$$\text{dose} = 4.110 \text{ rem} + 2.466 \text{ rem} = \underline{6.576 \text{ rem}}$$

- B. BONE - The average amount of radiation a human's bones would receive if unexposed on the lunar surface during years of low solar activity is 19 rem/yr (Guerra, L., 1987).

1.) 30-days on moon 19 rem/yr = 0.052 rem/day

$$\text{dose} = (0.052 \text{ rem/day})(30 \text{ days}) = 1.562 \text{ rem}$$

2.) Transit time 18 days

$$\text{dose} = (0.052 \text{ rem/day})(18 \text{ days}) = 0.936 \text{ rem}$$

3.) Total

$$\text{dose} = 1.562 \text{ rem} + 0.936 \text{ rem} = \underline{2.498 \text{ rem}}$$

APPENDIX F

THE TIN CAN DESIGN

OVERALL

The basic configuration of this design was shown earlier in the design options portion of this report. However, there is an error in the picture because each floor is 8 ft tall. This consists of piling regolith up against the vehicle until the first floor is covered thus making the first floor a safehaven. The shield collar will rest on the regolith as shown in Figure F-1. The ceiling of the first floor is the shield wall.

Some of the features of this design include a dumb waiter which will be used to move things between floors. The passage between floors is a three foot diameter hole in the center of each floor pole or ladder will be placed in it. All pressure doors in the vehicle can be opened from both sides of the door. All computers in the vehicle are networked together. A very limited attempt to balance the mass of the internal systems about the center of the vehicle was made.

FIRST FLOOR

The first floor will be covered with regolith to make a safehaven. The ceiling of the first floor is the shield wall. As is shown in figure F-2 the bedrooms are on the first floor. Each bedroom has two beds and personal storage space located against the wall and above the beds. The beds are 7 ft x 2.5 ft at the longest edge. The personal storage and workstation will probably consist of shelving or lightweight cabinet structures. The workstation will contain one personal computer which will be networked to all other computers in the vehicle. The computer will have a flat screen

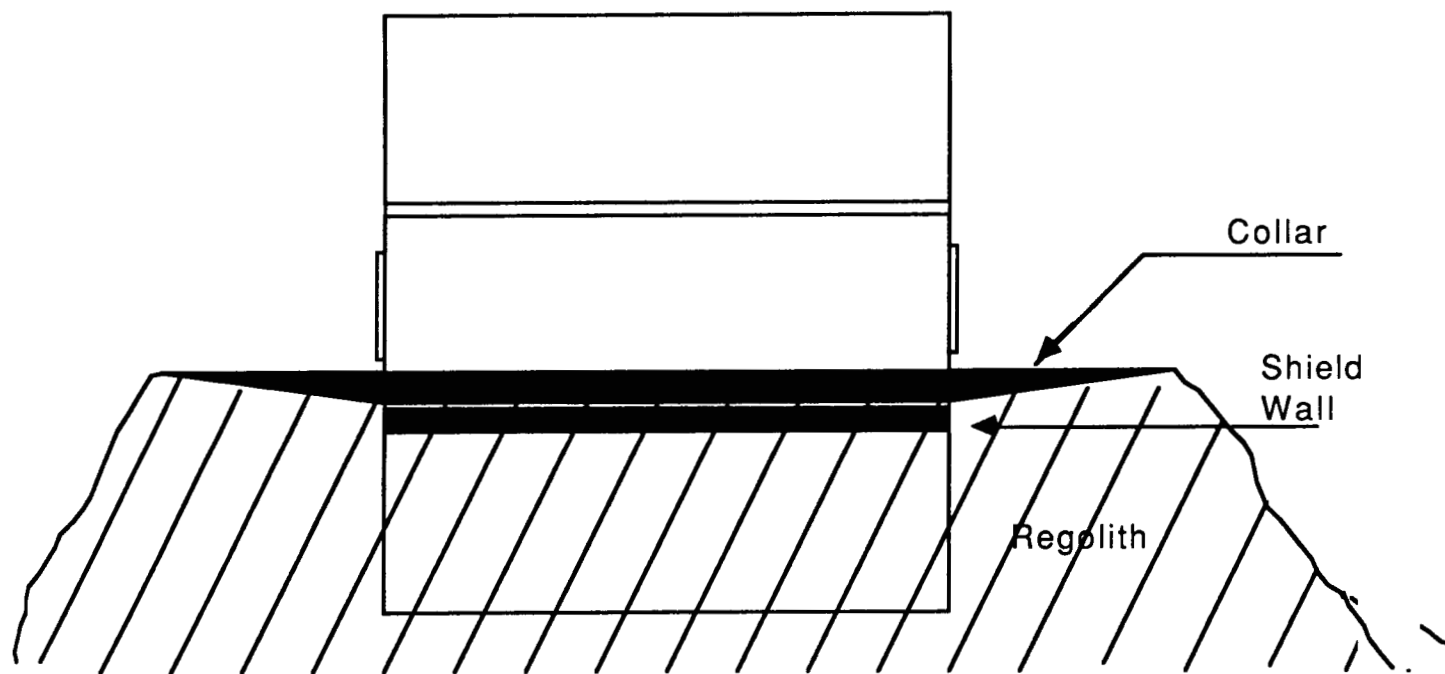


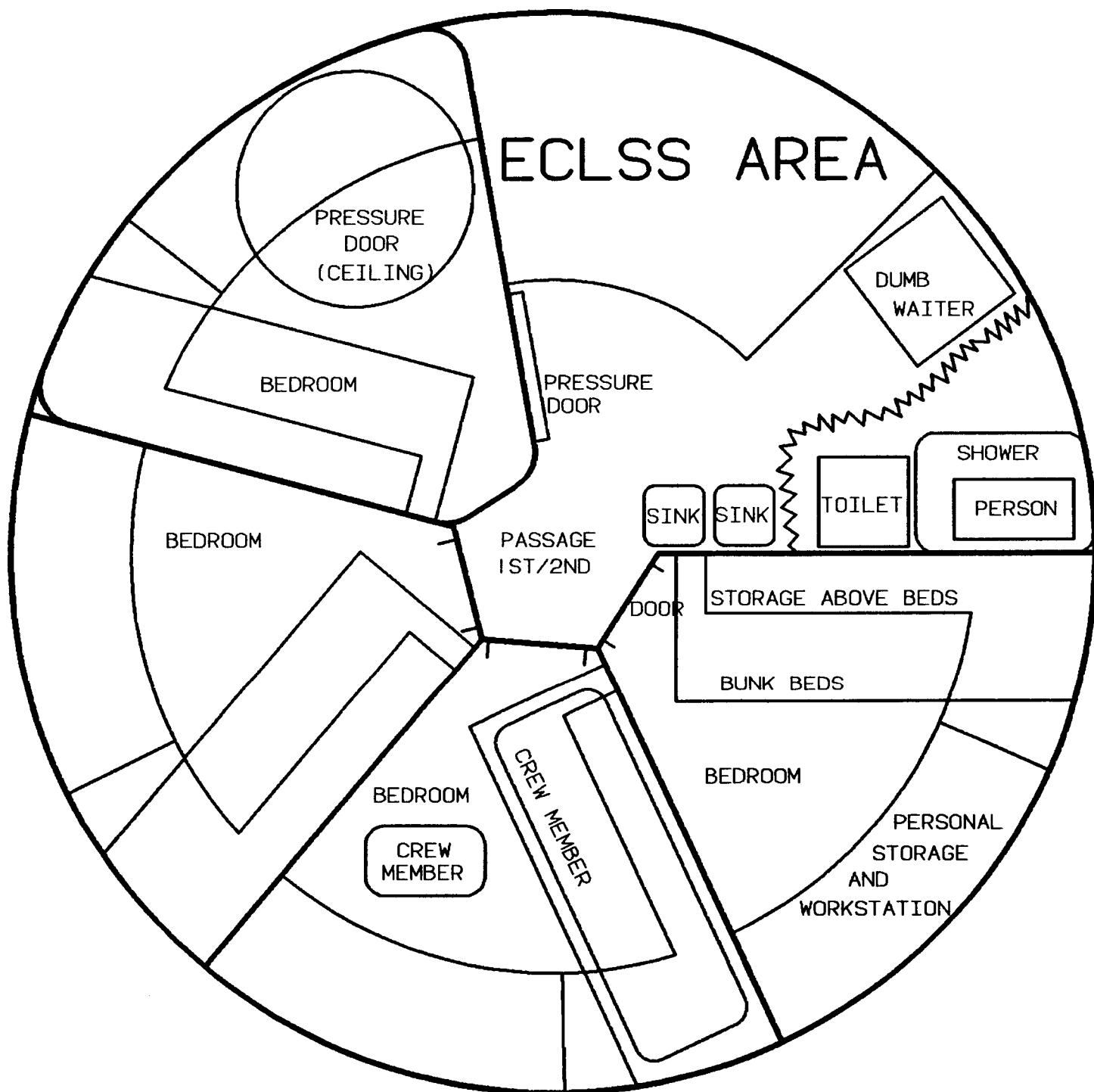
Figure F-1. Overall Configuration of Tin Can.

FIRST FLOOR (SAFEHAVEN)

VOLUME = 58.36 CUBIC METERS = 2060.71 CUBIC FEET

HEIGHT = 2.44 M = 8.00 FT

RADIUS = 2.76 M = 9.06 FT



Figur F-2.

display in order to cut down the space required by the computer monitor. A desk top can be pulled out from the storage area when needed. The crew members, one shown standing and the other lying on a bed, in one of the bedrooms is a 1.17 ft x 2 ft x 6.17 ft person.

Each bedroom will also contain enough dry food for two people for 4 days in case the crew should be confined to the first floor.

One of the bedrooms also doubles as an airlock. The pressure door in the bedroom ceiling emerges inside the airlock on the second floor and can be opened from both sides. This allows a quick access to the safehaven in case solar flare occurred and the astronauts received no warning. The door opens into the first floor to allow the pressure in the first floor to force the door closed when the second floor airlock is depressurized. In case of emergency, the first floor pressure door into the bedroom would be closed and the pressure door in the bedroom ceiling opened from inside the airlock. Once all astronauts were inside the bedroom, the ceiling door would be closed and the bedroom pressurized. Alarms will sound in the bedroom if there is an attempt to open the ceiling pressure door.

There is also the possibility that an exterior door can be put in the bedroom wall to allow access to the lunar surface from the bedroom. This option would be considered if the vehicle was not going to be buried at all. However, it would probably be best to simply switch the first and second floors.

The Environmental Control and Life Support System is also on the first floor. This allows access to ECLSS if the crew should ever be confined to the first floor. The ECLSS is also located below the storage area on the second floor. Oxygen and Hydrogen will be pumped down from the second floor but there will also be an emergency supply of oxygen in the first

floor.

The bathroom on the first floor is also located beneath the water tank on the second floor. This reduces the amount of piping to the shower and sinks in the bathroom. The bathroom contains a shower, two sinks, and a chemical toilet. The shower and toilet can be closed off with a curtain.

SECOND FLOOR

The main airlock is located on the second floor, as shown in figure F-3. There is storage space for eight space suits in the EVA staging area. The pressure door in the staging area ceiling emerges in the third floor airlock. The pressure door in the floor of the airlock emerges the bedroom/airlock on the first floor.

The resupply area also acts as a secondary airlock if necessary. The main purpose of this airlock is to act as a resupply hatch. This configuration allows resupply to take place without obstructing the crew's activities. Only three storage tanks are shown in resupply area but at least four more can be stored in the same area if necessary. Each storage tank shown in figure F-3 was sized to hold 100 gallons of water, but will also be used to store Oxygen and Hydrogen. The food storage areas have room for a four week supply of food. There will also be this amount of food storage in the galley on the third floor. In actuality, when the vehicle first leaves the earth it would be supplied with eight weeks worth of food. Then the ship can be resupplied as the food is cycled from the storage area into the galley. This also allows an extra supply of food in case a launch window for resupply is missed.

The fuel cells are stacked two high which yields a total of four fuel cells on the second floor. One Oxygen and One Hydrogen tank will contain

SECOND FLOOR

VOLUME = 58.36 CUBIC METERS = 2060.71 CUBIC FEET
 HEIGHT = 2.44 M = 8.00 FT
 RADIUS = 2.76 M = 9.06 FT

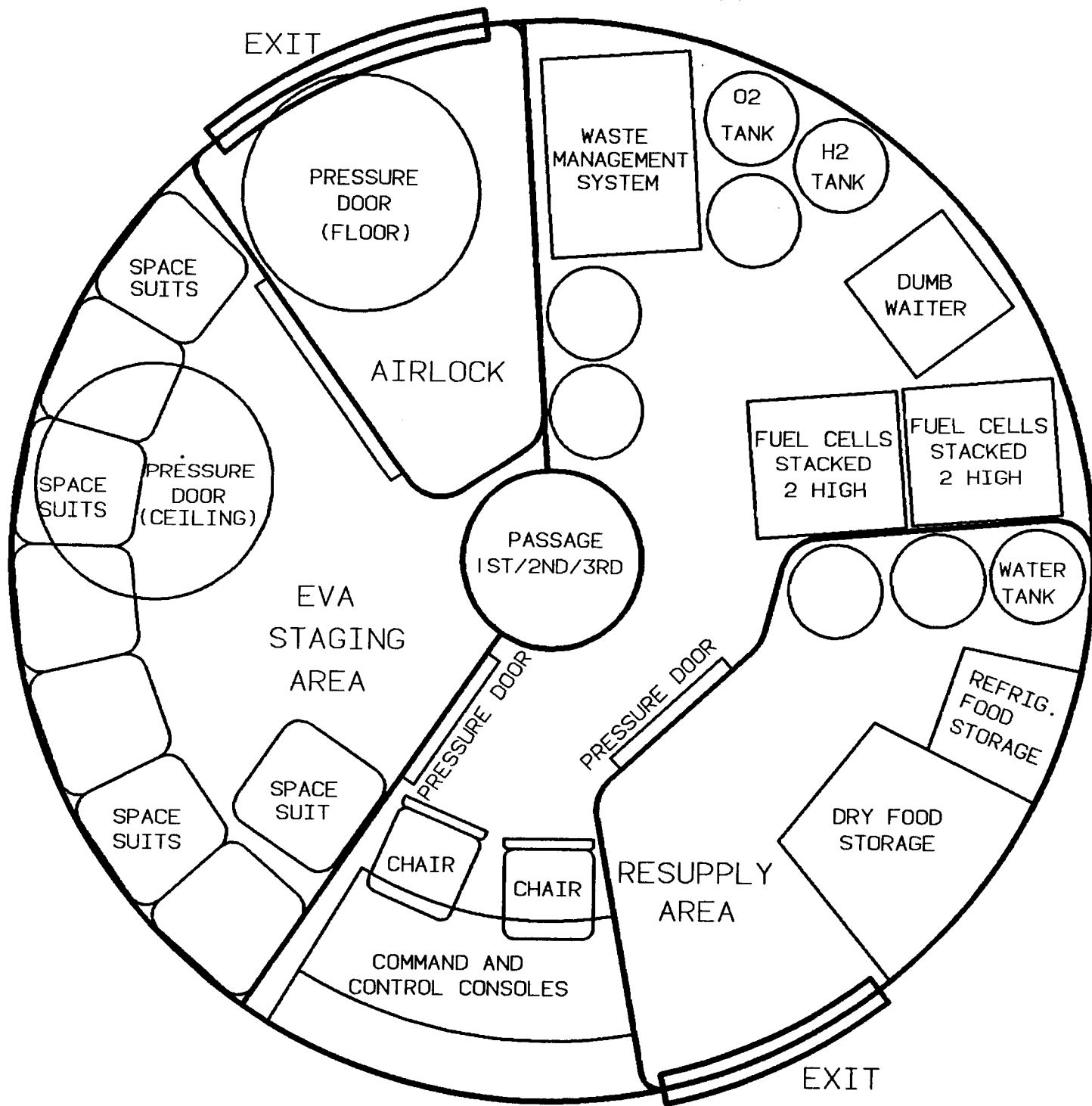


Figure F-3.

enough fuel to power the fuel cells for a week. These will be switched out when necessary. Empty tanks will be refilled from the fuel tanks located outside on the lunar surface. Across from the fuel cells is the waste management system.

The command and control area on the second floor will allow the crew to monitor the spacecraft systems. There will be at least four flat screen display monitors and two workstations in this area. The computers in this area will be networked to every other computer on the vehicle. The chairs shown in the command and control area have 1.5 ft x 1.5 ft seats with a two inch backrest.

THIRD FLOOR

The galley on the third floor contains a sink, refrigerator, trash compactor, washer and dryer, and oven, as shown in figure F-4. The refrigerator has enough space for four weeks worth of food. There are storage areas above the table and eating area and from ceiling to floor from the end of the table to the airlock. The total storage space holds four weeks worth of food. The table seats eight people and can be folded up and stored when not needed.

The sink, washer, and shower are located above the storage area on the second floor. This is to reduce the amount of piping needed to supply these facilities with water. The shower and chemical toilet can be sectioned off with a curtain.

The third floor airlock leads to the roof. This is to allow setup and servicing of the communication antenna, solar cells, and flood lights on the roof. The pressure door in the floor of the airlock emerges in the staging area on the second floor.

THIRD FLOOR

VOLUME = 58.36 CUBIC METERS = 2060.71 CUBIC FEET
 HEIGHT = 2.44 M = 8.00 FT
 RADIUS = 2.76 M = 9.06 FT

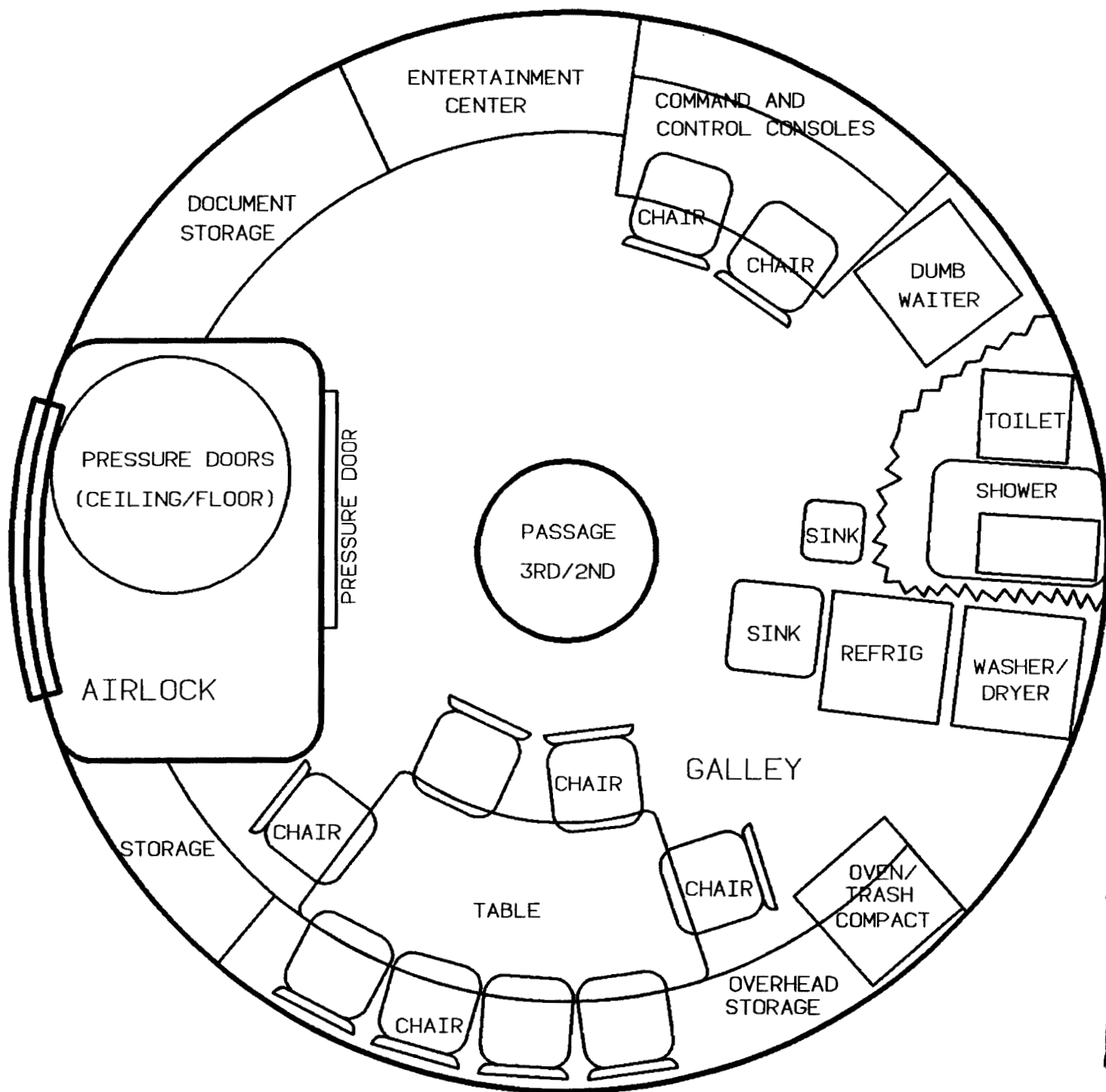


Figure F-4.

The command and control area resembles the one on the second floor but is a bit larger. The computers in this area are also networked with every other computer on the ship.

The rest of the wall storage space is used for an entertainment center and any other storage space which may be needed. This other storage space includes space for exercise equipment, any document storage such as plans for the lunar base, and storage for soft pressure suits. The third floor will mostly be used as recreational and meeting space.

ROOF

The communication antenna is located on the roof, figure F-5. There are also solar cells on the roof which can be set up on passive sun tracking mechanisms. This system will be used to supplement the power supply during lunar day. There are also flood lights located around the edge of the vehicle spaced 45° apart. These lights are needed to illuminate the working site during the lunar night.

ROOF

AREA = 23.93 SQUARE METERS = 257.59 SQUARE FEET
RADIUS = 2.76 M = 9.06 FT

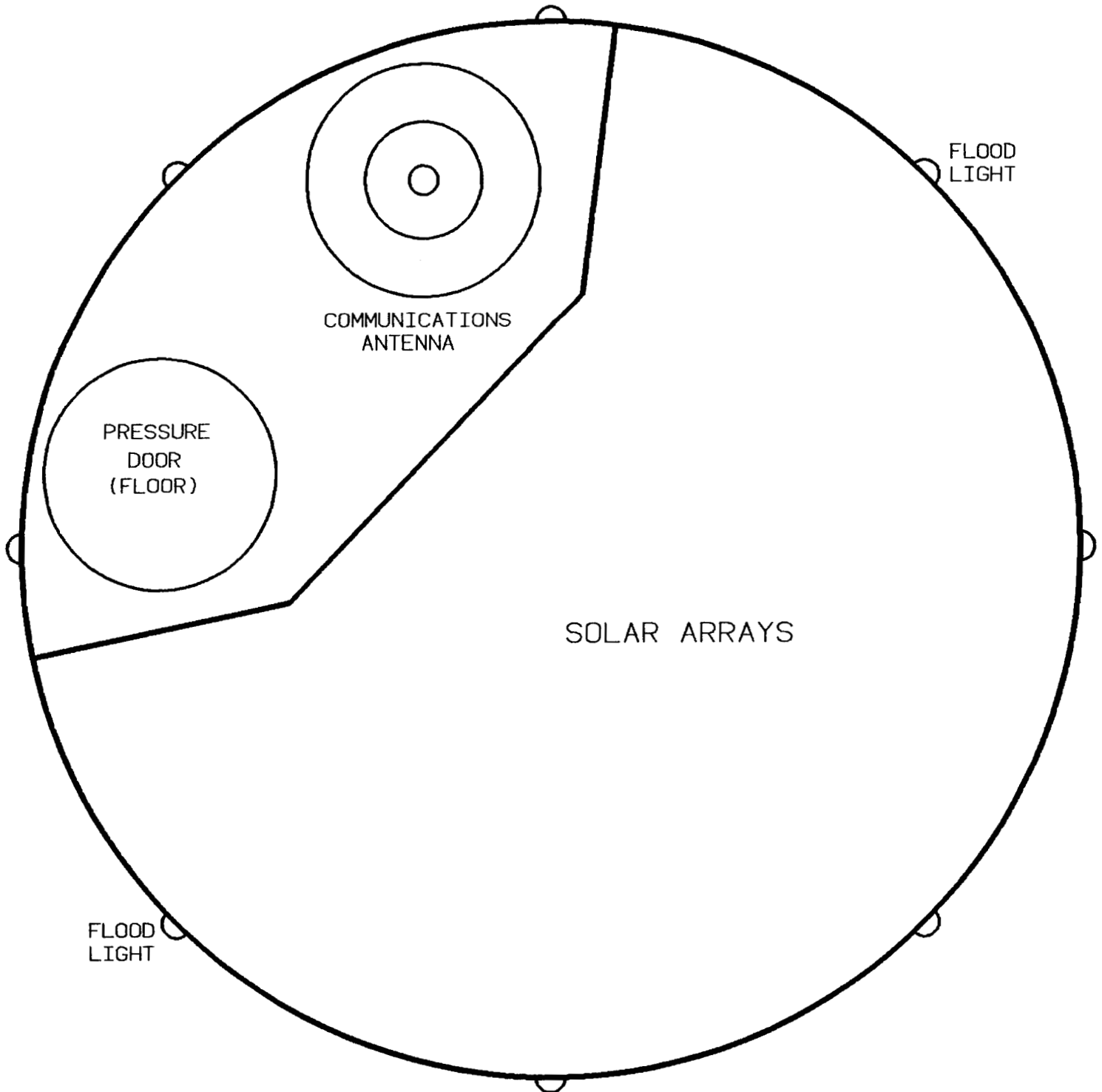


Figure F-5.

SPECIFICATIONS LIST FOR TIN CAN

I. OVERALL DIMENSIONS

A. Outer Dimensions

1. radius = 2.81 m = 9.22 ft
2. height = 7.67 m = 25.17 ft

B. Inner Dimensions

1. radius = 2.76 m = 9.06 ft
2. height (each floor) = 2.44 m = 8 ft
3. first floor ceiling thickness = 0.25 m = 0.83 ft = 10 in
4. second floor ceiling thickness = 0.05 m = 0.17 ft = 2 in
5. vehicle roof and bottom thicknesses = 0.05 m = 0.17 ft = 2 in

II. TOTAL VOLUME

- A. Internal Volume $175.08 \text{ m}^3 = 6182.13 \text{ ft}^3$

III. INTERNALS

- A. FIRST FLOOR (volume = $58.36 \text{ m}^3 = 2060.71 \text{ ft}^3$)

1. Each Bedroom

- (a.) Volume = $10.3 \text{ m}^3 = 363.92 \text{ ft}^3$
- (b.) Beds (length x width) = 2.13 m x 0.76 m = 7 ft x 2.5 ft
- (c.) Personal Storage Volume (includes personal computer and possible desktop area) = $3.28 \text{ m}^3 = 115.74 \text{ ft}^3$

2. Environmental Control and Life Support Systems

- (a.) Volume = $6.64 \text{ m}^3 = 234.55 \text{ ft}^3$

3. Bedroom/Airlock

- (a.) Volume = $10.3 \text{ m}^3 = 363.92 \text{ ft}^3$
- (b.) Pressure Door into Bedroom (width x height) =
0.76 m x 1.52 m = 2.5 ft x 5 ft
- (c.) Pressure Door in Ceiling (diameter) = 1.22 m = 4 ft

4. Bathroom

- (a.) Volume = $4.36 \text{ m}^3 = 153.93 \text{ ft}^3$

- (b.) Shower = $0.61 \text{ m} \times .92 \text{ m} = 2 \text{ ft} \times 3 \text{ ft}$
- (c.) Toilet = $0.46 \text{ m} \times 0.46 \text{ m} = 1.5 \text{ ft} \times 1.5 \text{ ft}$
- (d.) Each Sink = $0.30 \text{ m} \times 0.30 \text{ m} = 1 \text{ ft} \times 1 \text{ ft}$
- 5. Passage (diameter) = $0.91 \text{ m} = 3 \text{ ft}$

B. SECOND FLOOR (volume = $58.36 \text{ m}^3 = 2060.71 \text{ ft}^3$)

1. EVA Staging Area

- (a.) Volume = $11.06 \text{ m}^3 = 390.65 \text{ ft}^3$
- (b.) Each Space Suit (length x width x height) =
 $0.61 \text{ m} \times 0.61 \text{ m} \times 2.13 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 7 \text{ ft}$
- (c.) Airlock Exit Door (width x height) = $1.52 \text{ m} \times 1.52 \text{ m} = 5 \text{ ft} \times 5 \text{ ft}$
- (d.) Pressure door into airlock (width x height) =
 $1.22 \text{ m} \times 1.52 \text{ m} = 4 \text{ ft} \times 5 \text{ ft}$
- (d.) Pressure Door in ceiling (diameter) = $1.22 \text{ m} = 4 \text{ ft}$
- (e.) Pressure Door in floor (diameter) = $1.22 \text{ m} = 4 \text{ ft}$
- (f.) Pressure Door into EVA Staging Area (width x height) =
 $0.76 \text{ m} \times 1.52 \text{ m} = 2.5 \text{ ft} \times 5 \text{ ft}$
- (g.) Airlock Volume = $4.00 \text{ m}^3 = 141.25 \text{ ft}^3$

2. Waste Management System (length x width x height) =
 $1.02 \text{ m} \times 0.76 \text{ m} \times 1.17 \text{ m} = 3.33 \text{ ft} \times 2.5 \text{ ft} \times 3.83 \text{ ft}$

3. Each Fuel Cell (length x width x height) =
 $0.53 \text{ m} \times 0.71 \text{ m} \times 0.76 \text{ m} = 1.75 \text{ ft} \times 2.33 \text{ ft} \times 2.5 \text{ ft}$

4. Storage Tanks

- (a.) Volume = $0.38 \text{ m}^3 = 13.37 \text{ ft}^3$
- (b.) Size (diameter, height) = $0.48 \text{ m}, 2.13 \text{ m} = 1.56 \text{ ft}, 7 \text{ ft}$

5. Food Storage (refrigerated and dry)

- (a.) Volume = $2.462 \text{ m}^3 = 86.94 \text{ ft}^3$

6. Dumb Waiter (length x width x height) =

$$0.61 \text{ m} \times 0.61 \text{ m} \times 2.29 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 7.5 \text{ ft}$$

7. Resupply Area Volume = $12.08 \text{ m}^3 = 426.56 \text{ ft}^3$

8. Resupply Area Exit (width x height) = $1.22 \text{ m} \times 1.52 \text{ m} = 4 \text{ ft} \times 5 \text{ ft}$

9. Pressure Door into Resupply Area (width x height) =
 $0.76 \text{ m} \times 1.52 \text{ m} = 2.5 \text{ ft} \times 5 \text{ ft}$

10. Command and Control Area

(a.) Volume = $6.52 \text{ m}^3 = 230.09 \text{ ft}^3$

(b.) Each Chair Seat (width x length) = $0.46 \text{ m} \times 0.46 \text{ m} =$
 $1.5 \text{ ft} \times 1.5 \text{ ft}$

(c.) Desk Surface Area (Desk is 2 ft wide) =
 $0.95 \text{ m}^2 = 10.24 \text{ ft}^2$

C. THIRD FLOOR (volume = $58.36 \text{ m}^3 = 2060.71 \text{ ft}^3$)

1. Bathroom

(a.) Volume = $4.36 \text{ m}^3 = 153.93 \text{ ft}^3$

(b.) Shower = $0.61 \text{ m} \times .92 \text{ m} = 2 \text{ ft} \times 3 \text{ ft}$

(c.) Toilet = $0.46 \text{ m} \times 0.46 \text{ m} = 1.5 \text{ ft} \times 1.5 \text{ ft}$

(d.) Sink = $0.30 \text{ m} \times 0.30 \text{ m} = 1 \text{ ft} \times 1 \text{ ft}$

2. Galley

(a.) Volume = $21.42 \text{ m}^3 = 756.32 \text{ ft}^3$

(b.) Table Surface Area = $1.63 \text{ m}^2 = 17.53 \text{ ft}^2$

(c.) Dry Food Storage Volume (storage area is 2 ft wide) =
 $2.19 \text{ m}^3 = 77.34 \text{ ft}^3$

(d.) Refrigerator (width x length x height) =
 $0.61 \text{ m} \times 0.61 \text{ m} \times 2.13 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 7 \text{ ft}$
(volume = $0.79 \text{ m}^3 = 28.00 \text{ ft}^3$)

(e.) Washer (width x length x height) =
 $0.61 \text{ m} \times 0.61 \text{ m} \times 0.91 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 3 \text{ ft}$

(f.) Dryer (width x length x height) =
 $0.61 \text{ m} \times 0.61 \text{ m} \times 0.91 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 3 \text{ ft}$

(g.) Trash Compactor (width x length x height) =
 $0.61 \text{ m} \times 0.61 \text{ m} \times 0.61 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 2 \text{ ft}$

(h.) Oven (width x length x height) =
 $0.61 \text{ m} \times 0.61 \text{ m} \times 1.22 \text{ m} = 2 \text{ ft} \times 2 \text{ ft} \times 4 \text{ ft}$

(i.) Sink (width x length x height) =
 $0.46 \text{ m} \times 0.46 \text{ m} \times 0.46 \text{ m} = 1.5 \text{ ft} \times 1.5 \text{ ft} \times 1.5 \text{ ft}$

(j.) Each Chair Seat (width x length) = $0.46 \text{ m} \times 0.46 \text{ m} =$
 $1.5 \text{ ft} \times 1.5 \text{ ft}$

3. Airlock

(a.) Volume = $6.75 \text{ m}^3 = 238.23 \text{ ft}^3$

(b.) Pressure Door in Floor and Ceiling (diameter) =
 $1.22 \text{ m} = 4 \text{ ft}$

(c.) Pressure Door into Airlock (width x height) =
 $1.22 \text{ m} \times 1.52 \text{ m} = 4 \text{ ft} \times 5 \text{ ft}$

(d.) Pressure Door to Outside (width x height) =
 $1.52 \text{ m} \times 1.52 \text{ m} = 5 \text{ ft} \times 5 \text{ ft}$

4. Command and Control Center

(a.) Volume = $6.52 \text{ m}^3 = 230.09 \text{ ft}^3$

(b.) Each Chair Seat (width x length) = $0.46 \text{ m} \times 0.46 \text{ m} =$
 $1.5 \text{ ft} \times 1.5 \text{ ft}$

(c.) Desk Surface Area (Desk is 2 ft wide) =
 $0.95 \text{ m}^2 = 10.24 \text{ ft}^2$

5. Extra Storage Space (storage area is 2 ft wide) =
 $4.33 \text{ m}^3 = 153.03 \text{ ft}^3$

Appendix G
Project Proposal

1.0 General Summary

This proposal is submitted in response to the RFP 274L for a Lunar Lander / Shack Vehicle by the Selene Engineering Company (SEC) of Austin, Texas. An overview of SEC's approach to the technical and management tasks will be discussed, including a cost proposal and project schedule.

1.2 Project Background

A permanent lunar base would serve as an outpost for scientific research and for the exploitation of the moon's material resources. It would also serve as a testing ground for technologies needed for the exploration of Mars or the outer planets. The possibility of its being self-supporting through the production and shipment of liquid oxygen to earth orbit has been discussed and this, coupled with the unparalleled astronomical and geo/selenological research opportunities presented by a lunar base provide ample justification for its construction.

The first step in the construction of a lunar base will be selecting a site and transporting the construction materials to that site on the lunar surface. The second step will be to land a construction crew on the surface and support them while they begin assembling the pieces of the base into a habitable structure. This proposal addresses some of the technical problems of this second step.

1.2 Design Overview

The Lunar Lander / Shack Vehicle, as envisioned by SEC, will be a comfortable, safe and functional habitat for the initial construction crew. Vehicle mass and performance will be optimized so that it can be delivered to

the lunar surface for the lowest cost. Eventual integration of structural parts and sub-systems into the Moonbase design will be a primary consideration.

The technical design submitted at the completion of the contract will be in the form of a detailed scale model and plans for the vehicle and accompanying documentation. The design tasks will be addressed by two teams: Spacecraft Design and Human Engineering. The operation of the two design teams assigned to the project will be overlapped as much as possible to ensure the smooth integration of all sub-systems into the overall vehicle design.

The Spacecraft Design Team will design the vehicle's engine and stage configuration and will outline descent and ascent propulsion requirements. This Team will also be calculating propellant requirements and sizing the necessary tanks and cryogenic systems.

The Human Engineering Team will be assigned the task of designing all life support systems. This team will be responsible for consumables, waste management, radiation shielding, heat management and power requirements. Fail-safe and redundant systems will be a primary design criteria for all life support systems.

1.3 Design Assumptions and Requirements

The following assumptions will be made in SEC's design for the lunar lander:

- Earthport is fully operational and capable of assembling the lander in orbit
- A vehicle capable of transporting the lander and crew from Earth orbit to lunar orbit exists and has been tested
- The moonbase site has been selected and mapped
- All necessary construction materials for the construction of the Moonbase have been delivered to the site

Lander Design Requirements:

- Vehicle must provide living quarters on the moon for a crew of eight for three weeks.
- Vehicle must provide radiation shielding in the case of a solar flare
- Any vehicle portion which will not be returned to lunar orbit with the crew must be usable as an integral part of the Moonbase

2.0 Technical Proposal

SEC proposes to design a self-sufficient facility which will land on the lunar surface from a lower lunar orbit and support a crew of eight people for three weeks while they begin construction of a lunar base. The vehicle design will also provide for crew return to lower lunar orbit in the event of an emergency or the completion of the mission. It is assumed that transportation of the lunar shack and crew from earth has been provided by either an orbital transfer vehicle or lunar transportation node.

2.1 Technical Design Overview

The design of the lunar shack is divided into two areas: Spacecraft Design and Human Engineering. The responsibilities of the two design groups will overlap and the design will be fully integrated.

2.2 Spacecraft Design

The primary design option SEC is considering is shown in Figure 1. This option consists of the vehicle landing on the lunar surface with the crew aboard the living quarters of the shack. The living quarters will remain mounted on the descent stage throughout the duration of the mission. The descent stage will be used as a launch pad for the living quarters/ascent vehicle in the event of an emergency or completion of the mission.

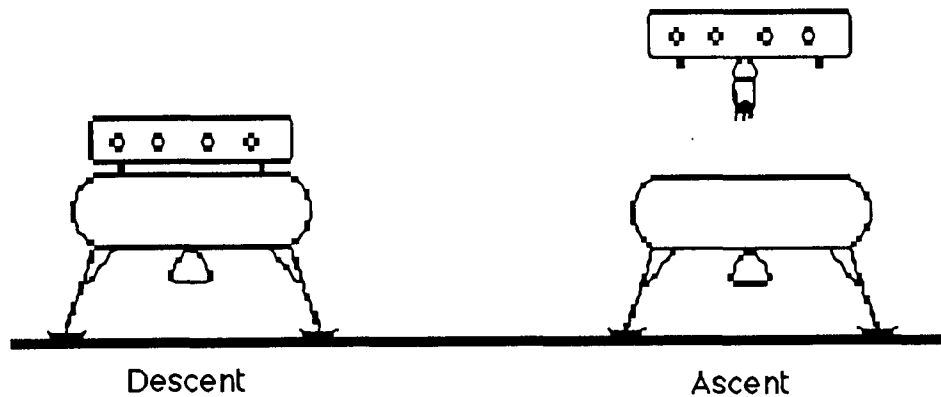


Figure 1. Primary Lander Option

Other design options are found in Figure 2. A matrix of possible lander designs versus design criteria, and the weighting factors for these criteria are found in Table 1. From the totals for each lander, it can be seen that two additional lander designs are worth consideration. One depicts the vehicle with an escape node mounted on top of the living quarters for landing, and the escape vehicle alone providing the ascent to lower lunar orbit. Another design possibility is that of two separate vehicles (the lunar shack/living quarters and the escape node) landing on the lunar surface. This escape node is similar to the above design, in that it alone would provide ascent to lower lunar orbit.

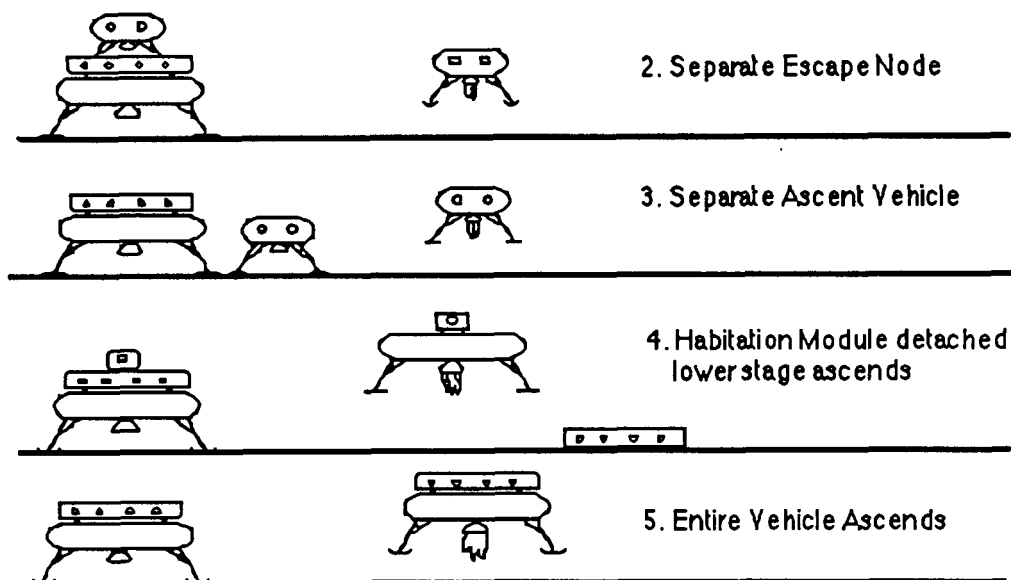


Figure 2. Lander Design Options

Lander Designs

Criteria	1	2	3	4	5
State of Ascent Engines	5	5	2	1	1
Ascent Weight (x2)	3	5	5	3	0
Descent Engines (x3)	3	2	1	2	1
Life Support/EVA (x3)	4	2	2	2	4
Number of systems	3	2	1	1	4
Reliability and redundancy	4	4	4	1	2
Lunar base interfacing	5	2	5	5	2
Volume	4	3	3	2	1
Total	45	40	37	24	23

good bad
5 4 3 2 1 0

Table I. Lander Configuration Decision Matrix

2.2.1 Propulsion

The vehicle's engines are a critical system which cannot fail without jeopardizing the crew or the mission. The designs chosen will have to be highly reliable and the fuel system will have to be stable and storable due to the length of the mission. SEC's design approach will be to assume no major technological advances in engine design will be necessary before the construction of the lander's engines and, if possible, will use existing engine designs or slightly modified designs.

The performance required is dependent on the necessary delta V's. The engines will be required to perform three maneuvers: De-orbiting from LLO, braking and hovering as the vehicle approaches the surface and ascent from the surface back to LLO. The descent and ascent requirements are very different and will be considered separately.

2.2.1.1 Descent Engines

The descent phase of the flight involves de-coupling from the lunar transportation node and decelerating from the orbit velocity as well as braking and maneuvering near the lunar surface. The descent engines of the vehicle will, therefore, be needed to perform two burns and will need to be throttleable and gimballed to facilitate braking and maneuvering.

In the three primary vehicle configurations being considered, the descent engines will not be reused in the ascent from the lunar surface. Any possible integration of this system into the lunar base will depend, therefore, on its being modular and interchangeable with projected base hardware. The descent engines could be reused as spares or be dismantled for their parts.

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2.2.1.2. Ascent Engines

Any failure of the ascent engines will result in the stranding of the crew on the lunar surface. Reliability will, therefore, be the primary concern in their design. Other important factors will be the weight of the engines and the storability of the fuel. The weight factor is doubly important for the ascent engines because they will be carried through the round trip from LLO to the surface and back to LLO.

The fuel will need to be very stable and storable on the lunar surface due to the minimum three week surface stay required. The possibility of using solid rocket motors for the ascent stage will be investigated owing to their high reliability and fuel stability. Provisions for monitoring the condition of the fuel and ascent engines during the time on the surface will be necessary to head-off any degradation which might occur.

2.2.1.3 Refueling

Refueling and refitting the vehicle will be considered as an option for the ultimate use of the lander and not as a part of the lunar shack operation. The purpose of refueling the ascent stage would be to provide a crew transportation system between the lunar base and Moonport. A fully operational (un)manned Moonport is assumed to be in LLO.

In order to use the ascent stage as a transportation system, it should have reusable landing gear and highly reliable engines for multiple use. If the ascent stage does not have landing gear, it will have to be attached to the ascent stage at Moonport. The refueling procedure should be as safe as possible.

2.2.2 Trajectory and Navigation

Trajectory and navigation will consist of determining the flight path from low lunar orbit to the lunar surface and back. These calculations will produce rough numbers for calculating the fuel requirements.

2.2.3 Landing Gear and Guidance

A design specification of the landing gear is the structural support of the vehicle upon landing. The landing gear must also be reusable and able to withstand the forces exerted upon it by the ascent vehicle. A "tinker toy" design, in which the gear could be detached and used as beams in the construction of the lunar base, would serve this purpose.

Guidance systems will be required to facilitate a soft and accurate landing: Necessary determinations will be line of sight from the vehicle to the geometric center of the moon and an additional reference in order to completely determine the lunar vehicle velocity. Such a sensor must provide the vehicle altitude, vertical velocity vector, and lateral velocity vector.

2.3 Human Engineering

The area of human engineering is concerned with the life support requirements and surface support requirements for the spacecraft's crew. There are two constituent regions of research; 1) Life Support and, 2) Surface Requirements. The task of life support is to provide all necessary requirements to provide a habitable environment for the crew, either in transit or on the surface of the Moon, and what systems need to be provided. Surface Requirements is concerned with defining what the crew entails to conduct their operations, and methods to do such operations. All items assume a stay of approximately three weeks on the Lunar surface, and a transit time of five days.

2.3.1 Life Support

2.3.1.2 Consumables

The food consumption requirements for these two periods will be distinct both in content and in method of serving. The meals eaten as the crew is traveling to and from the Moon will be eaten in a weightless environment and will consequently be unique from the Moonbase meals. In calculating the amount of food required and the space this food will occupy, we will be using current NASA standards for Shuttle missions. The following amounts are given on a per person per day basis:

0.62 kg. food

3.35 kg. potable water

0.72 kg. of water added to food

This is a total of 3.69 kg. of food and water per person per day; a crew of eight on a mission of thirty days will require 885.6 kg. There will be a 20 % overage factor added to the food estimates to ensure the satisfaction of crew member. Thus the total mass of food supplies for the mission is estimated to be 1,062.72 kg.

Taking into consideration the amount of food needed, the number of crew members, and the equipment needed to prepare meals, it is estimated that 15-20 cubic meters will be needed for the galley / wardroom of the Lunar shack vehicle. This space will account for the storage, heating, and dispensing of all food and water supplies. The food types will include rehydratable, thermostabilized, frozen, and natural state foods.

Further types of consumables to be included are Oxygen and Nitrogen for environment, (discussed in Environmental Control and Life Support, Sec. 2.3.1.6), items for personal hygiene, non-potable water, medicines, and minor items such as replacement light bulbs.

2.3.1.3 Waste Management

On the surface, recycling of water from condensation, urine, and wash water may be a necessary and feasible option. The recycling options will depend on which type of system chosen for the shack design. Whether the shack has a completely open or partially closed system will dictate which recycling options to consider. A completely open system is very expensive to consider, not only because of the large quantities of Oxygen and water provisions needed, but also for the added weight of the expendables need for the removal and containment of carbon dioxide (CO₂). A partially closed system can be used on a mission of this length. Recycled water from condensers in the air-conditioning system, and multi-filtered water from the washing system can be used as drinking water. This water can also be used to created oxygen through electrolysis. Human wastes will be compacted for storage in either system. Due to the length of decomposition and filtering efforts for solid wastes, it is not foreseen that recycling of these wastes are a viable option for this mission.

It is estimated that the personal hygiene area of the Lunar vehicle will account for less than 10 % of the total volume of the ship. This figure takes into account washing facilities, evacuation facilities, and storage areas for personal hygiene accessories. As the development of the Lunar Shack design progresses the allowable and needed volume requirements will be further defined.

2.3.1.4 Radiation Shielding

Lunar radiation is a large problem. The types of radiation which must be considered are Galactic Cosmic Radiation and Solar Radiation. Galactic Cosmic Radiation originates from the galaxy and usually consists of very low intensity high energy particles. It is omni-directional, which infers that humans must be shielded on all sides and from underneath. Solar Radiation originates from the Sun, usually consisting of X-Rays, high energy proton streams, ultraviolet radiation, and form of radio interference. The most extreme cases of solar radiation occur during a solar flare. In this study the solar flare is considered a worst case and the shield will be designed to protect against it.

During a solar flare the Sun emits very high intensity radiation. This means an astronaut can receive a large amount of radiation in a short period of time. The dosage is often enough to kill. During a flare the radiation leaves the Sun at such high velocities that there is very little prior warning. A flare's radiation may cause radio interference and thus a black-out of communications.

2.3.1.4.1 Shield Design

The shield will be designed using the following equation:

$$I = I_0 e^{-mx}$$

where I_0 is the original radiation intensity, I is the final radiation intensity, m is the mass absorption coefficient for the material, and x is the material thickness. Thus by solving for I / I_0 one can find out how much a certain thickness of material reduces the intensity of incoming radiation. As the intensity of the particles is reduced, the amount of damage done by that particle is similarly reduced, and thus the dosage of radiation received from high energy particles can be reduced.

Mass absorption coefficients (μ) can be found in tables. Materials which have high values of μ at high levels of intensity are desirable.

The goal is to find shielding materials or combinations of materials which will reduce the intensity of from the highest energy radiation emitted during a solar flare to an intensity which will only give a human a 50 rem dose per year. There are many criteria which also must be considered in the shield design.

These are as follows:

- 1) Secondary Radiation - Some materials, usually metals and heavier elements, absorb radiation but then emit other forms of radiation which are lower in intensity but still dangerous.
- 2) Weight - The materials must have as low a net weight as possible.
- 3) Structurally or Otherwise Usable - The materials in the shield must serve purposes other than shielding.
- 4) Radiation Damage - Materials which do not deteriorate when exposed to radiation are desirable.
- 5) Melting Point - Materials which have a very high melting point are desirable.
- 6) Ease of Construction
- 7) Danger - Shields made from materials which may be combustible under certain conditions or are otherwise dangerous are undesirable.
- 8) Complexity - Shields which are extremely complex are undesirable.
- 9) Amount of Protection - Shields which provide a maximum of radiation protection are desirable.

The designs currently under consideration are variations on two main themes. The first is to have all the shielding built onto the shack vehicle. This will be sufficient to protect against a solar flare. Some materials being considered are : graphite, aluminum, silicon, water, copper, tin, magnesium, and paraffin.

The second design involves building only enough shielding onto the spacecraft to protect against normal radiation amounts. The additional

shielding will be in a shelter built over the shack when on the Moon's surface. This design may use the materials stated above and also Lunar regolith.

2.3.1.5 Heat Management and Thermal Control

The Heat Management and Thermal Control System is to provide a livable temperature regime for the spacecraft interior. Temperature ranges on the surface of the Moon may vary from 134⁰C. during Lunar day to -153⁰C. at Lunar night. The spacecraft must be protected from these extremes, must radiate unwanted or excess generative heat, and must be insulated to contain heat when ambient outside conditions are colder than in the spacecraft.

Some of the heat may be conducted through the atmosphere circulation system, with the excess heat being removed from the air. However, this will most likely not be adequate to remove all necessary heat. Therefore, water circulation loops will be employed throughout the spacecraft. The circulating coolant water, positioned in the cabin walls, will collect heat from various areas in the cabin (i.e. heat exchange elements), and continue to a freon coolant loop. Due to the toxic characteristics of freon, the freon loop will not be located in the cabin compartment. Consequently, it also may be utilized to cool any cryogenic storage facilities. Heat collected in this system can be passed to radiators or dissipation elements. These may be passive radiators, simple panels exposed to the Lunar environment or buried within the Lunar regolith, or active elements. Active elements may include an evaporative process, in which the heat is used to evaporate water, which is then released to the environment as a gas. Another method for thermal control is to cover the spacecraft's exterior with a highly reflective surface, such as an aluminized foil.

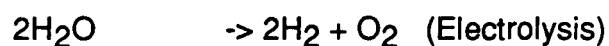
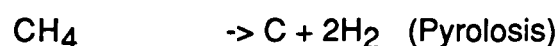
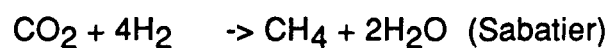
2.3.1.6 Environmental Control and Life Support

The Environmental Control and Life Support System (ECLSS) is used to provide and maintain a livable atmosphere within the spacecraft. An 80 % nitrogen, 20 % oxygen mixture will be used. This will reduce the probability of a large fire, and will reduce the total spacecraft mass; a nitrogen / oxygen mixture will be less massive than a similar 100% oxygen atmosphere. A normal sea-level (14 psi) pressure will be maintained, as will a nominally low humidity level of 20%.

The environment system will circulate and regenerate a breathable atmosphere in the following procedure:

1. Separation of carbon dioxide from the atmosphere
2. Decomposition of carbon dioxide into its elementary constituents, solid carbon and gaseous oxygen
3. Delivery of oxygen to cabin atmosphere
4. Disposal or storage of carbon

The first process, the removal of carbon dioxide, may be accomplished by circulating the atmosphere through a cell of lithium hydroxide, which acts as a scrubber. This is a light weight and relatively simple system, however it precludes the reclamation of oxygen.. Another method, one which would remove and recirculate oxygen, is the Sabatier system, a process shown below:



Except for a small initial supply of hydrogen, the required hydrogen would be regenerated by the process. The use of either system will be dictated by the total available power generation of the spacecraft (Sabatier requires 1.55 [kW-hr]/lb oxygen recovered. Carbon scrubbing requires less.)

The atmosphere will generally be circulated in one particular, yet constant, direction. Numerous sensors will be placed about the spacecraft, monitoring carbon dioxide levels, and humidity levels.

2.3.2 Surface Requirements

2.3.2.1 Communications

The Lunar Shack mission will require a communications network allowing voice, visual, and data transmission between all vehicles and mission support facilities. The Tracking and Data Relay Satellite System (TDRSS) deployed about Earth will eliminate line of sight communications interruptions. The TDRSS will link ground based mission facilities with the Earthport. Either the Earthport or TDRSS system itself will broadcast to the shack and transfer vehicle in transit to the Moon. The shack and Moonport will receive messages using radio dishes and will transmit to the TDRSS satellites. The shack will be able to transmit and receive messages sent to or from the Moonport and astronauts conducting surface operations.

This network approach to the communications systems design provides multiple paths to link all components of the mission. Any one component can communicate with any other. In this way, astronauts during EVA on the Lunar surface can communicate with or transmit data to ground based mission control.

2.3.2.2 Power Requirements

The system supplying power to the Lunar Shack will be required to do many operations. It must support all the spacecraft systems. It must support, to some degree, the surface operations of astronauts building the lunar base. It must provide back-up power for an emergency return to Lunar orbit in the event of failure of the primary power system. If power is to be generated on the Lunar surface, a supplementary power supply must support the shack and surface operations until the primary source is brought on-line.

There are three power supply systems under consideration:

1. Solar Cells - arrays deployed on the Lunar surface supplying storage batteries. Large power facilities will be needed since most of the Lunar surface alternates between two weeks of light and dark. Mass and volume of this system would tax transport capabilities.
2. Fuel Cells - electricity generated by the chemical process of electrolysis. Present technology may be utilized.
3. Lunar based nuclear plant with heat radiator and power converter/conditioner linked to the shack. This system would have a higher specific energy (Watts/kg) than the solar array. The extra weight of a nuclear system becomes cost effective at high power levels (25-40 KW).

There are a number of designs for nuclear power systems which will be considered. There are also different approaches for thermal to electric-energy nuclear fuels. Three space have been extensively tested the SNAP-8, SNAP-10A, and SP-100. The SP-100 design appears to be well adapted to the Lunar Shack mission.

2.3.2.3 Spacecraft Interior

Interior considerations for design will include the space and equipment requirements to operate efficiently while maintaining a minimum of volume. This includes the equipment required for control of surface operations and the basic human survival requirements of living space (sleeping, eating, hygiene, privacy, exercise, etc.). The floorplan will insure efficient use of the limited available space by utilizing folding or removable walls and stowable facilities (i.e. showers, tables). A drawing of the floorplan will be delivered at the the end of the project.

2.3.2.4 Emergency Contingencies

Provisions will be considered for possible procedures in case of the following emergencies:

1. Loss of environment (atmosphere, temperature, etc.)
2. Loss of primary power
3. Medical
4. Mechanical Malfunction of safety systems
5. Catastrophic failure (abort conditions)

Although these are beyond the scope of the project, any problems and/or requirements identified during design for the spacecraft/habitat will be noted.

2.3.2.5 Surface Operations

The operational requirements for basic surface operations include minimum spacesuit requirements, possible interface, and/or use with Lunar Traverse Vehicle and radiation event protection. The spacecraft exterior will accommodate the lighting, monitoring, and access requirements needed for the surface operations.

2.3.2.6 Physical and Mental Health

The morale of the crew is a major consideration in the design of the shack. A work shift schedule will be introduced to take into consideration crew fatigue, external radiation exposure and spacesuit limitations. These items are mission specific and depend upon concepts such as multiple job qualifications, different spacesuit design, and particular job being performed. Also, space requirements will provide for privacy, exercise, and recreation.

2.4 Summary

In summary, the Selene Engineering Company will deliver a CAD model and a physical model of the final design. Our design will incorporate the most advanced technology to produce a safe and reliable shack design. We will provide a floor plan of the vehicle and all accompanying documentation.

3.0 Management Proposal

3.1 Management Structure

The Selene Engineering Company consists of a Project Manager, an Operations Manager, two Team Leaders, and five Design Engineers. The Project Manager is responsible for the actions of the two design teams. He is in control of all administrative decisions and technical aspects of the development of the design. The Operations Manager is in charge of coordination of the efforts of the design team. All documentation of needs, accounting, and scheduling of tasks is handled by the Operations Manager. The Selene Engineering Company is divided into two groups: Spacecraft Design and Human Engineering. Each group has a Team Leader who is responsible for monitoring the activity of the engineers in their respective group. The Team Leaders are responsible for collecting, collating, and coordinating the data provided by the engineers. This structure is represented graphically in Figure 3.

3.2 Team Responsibilities

The Spacecraft Design Team is in control of the design and planning of the spacecraft configuration and the transportation system for the mission. The Human Engineering Team has responsibility for the definition of all needs to support the life and health of the crew and requirements to promote surface operations.

3.3 Management Purpose

This structure was chosen to enhance and facilitate communication between group members and the managers. In the event that any engineer requests a design change, this change is presented to the Team Leader. If the Team

Leader can not resolve a dispute he brings up this problem with the Project Manager. It is the Project Manager who is responsible for communicating any problems/questions to the Technical Advisor, George Davis, or the Project Advisor Dr. Fowler.

Organizational Chart
of the
Selene Engineering Company

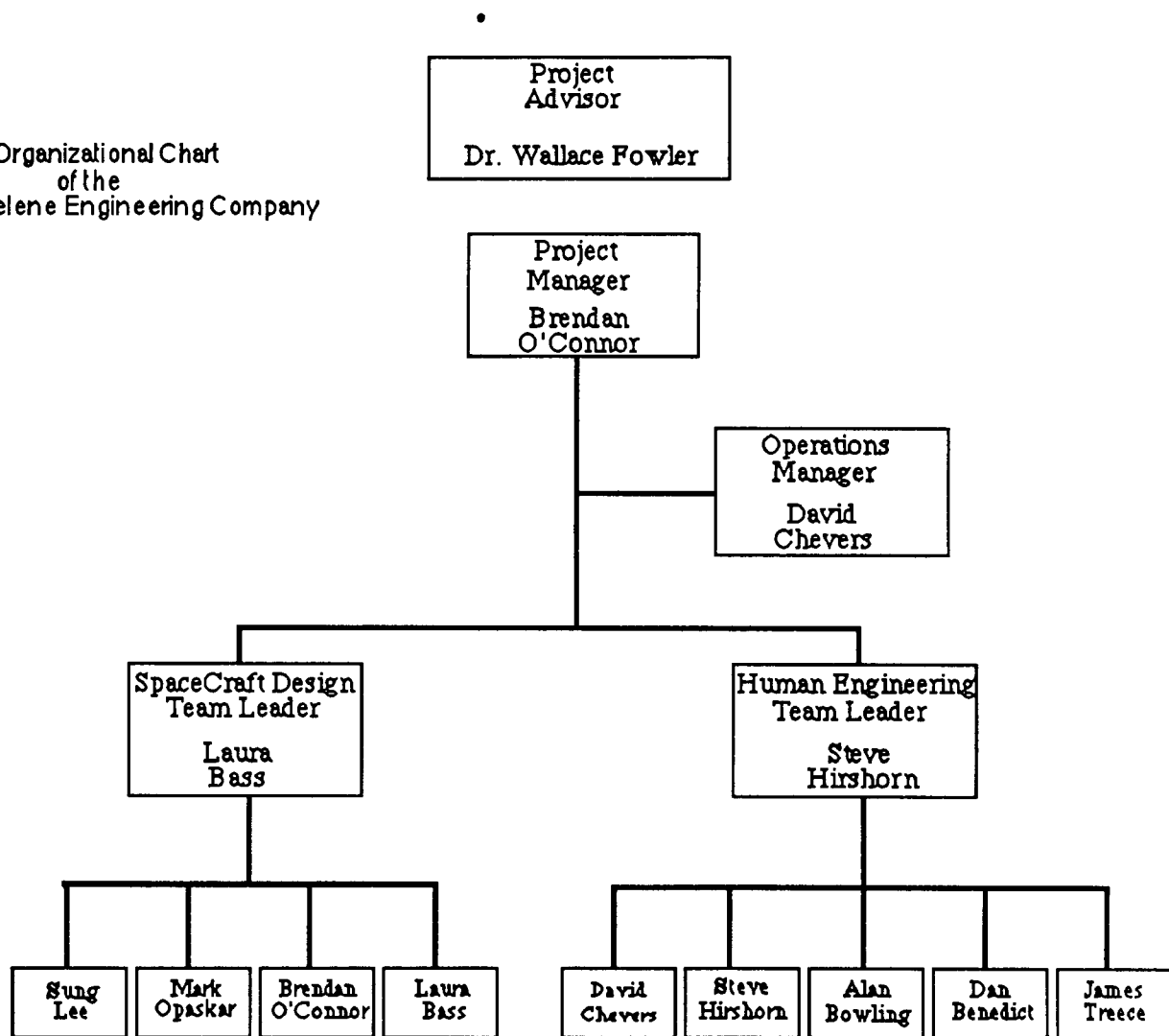


Figure 3. Organizational Chart

3.4 Workload Considerations

Due to the small size of SEC, each engineer may have many responsibilities. To monitor the workload of each member of the company a timesheet and a chart of workload constraints is being kept. This will help to monitor which areas are overemphasized and which areas are being neglected. The company has developed a milestone graph (Figure 4) for the design process to act as a guide for the progress that should be made by the team. Individual PERT charts are also made before each major step in the design process. A PERT chart of the present state of the design is shown in Figure 5. These charts ensure that all areas are covered and help the Project Manager in the allocation of manpower resources. We believe that this overall structure has proven to be beneficial and conducive to a good design process.

Projected Project Milestones Chart

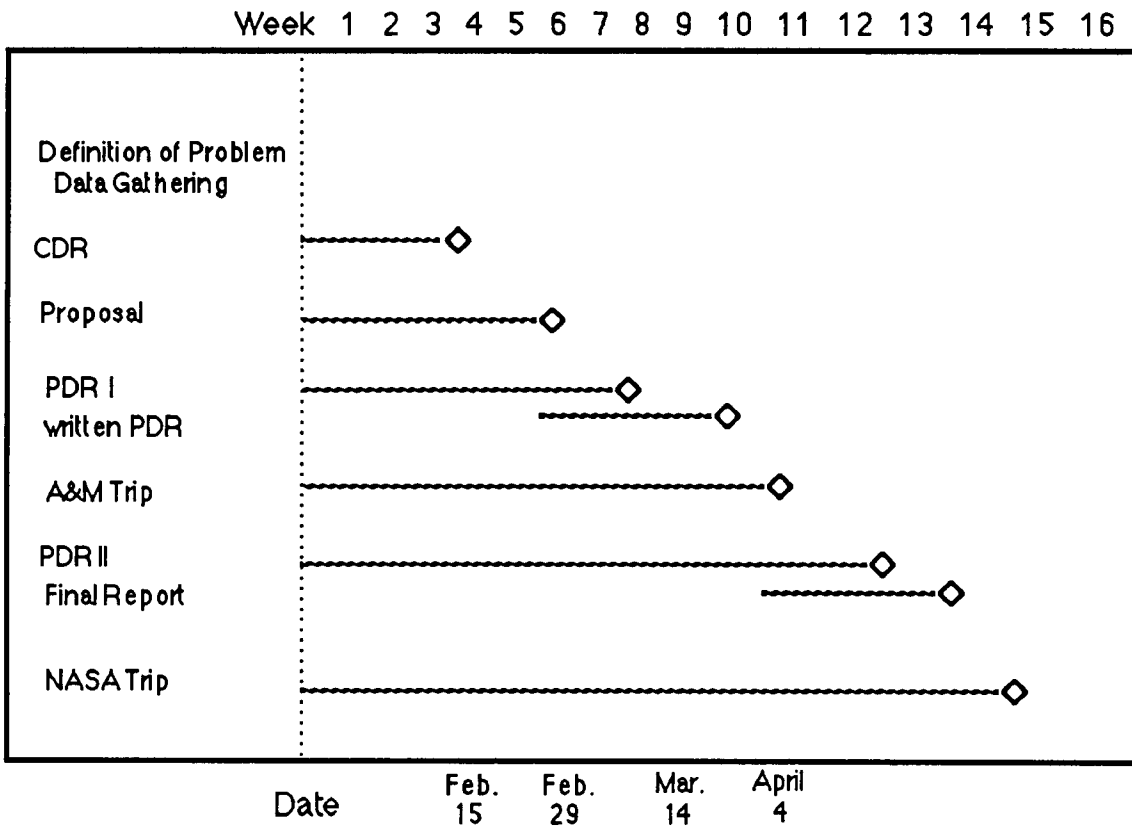


Figure 4. Project Milestone Graph

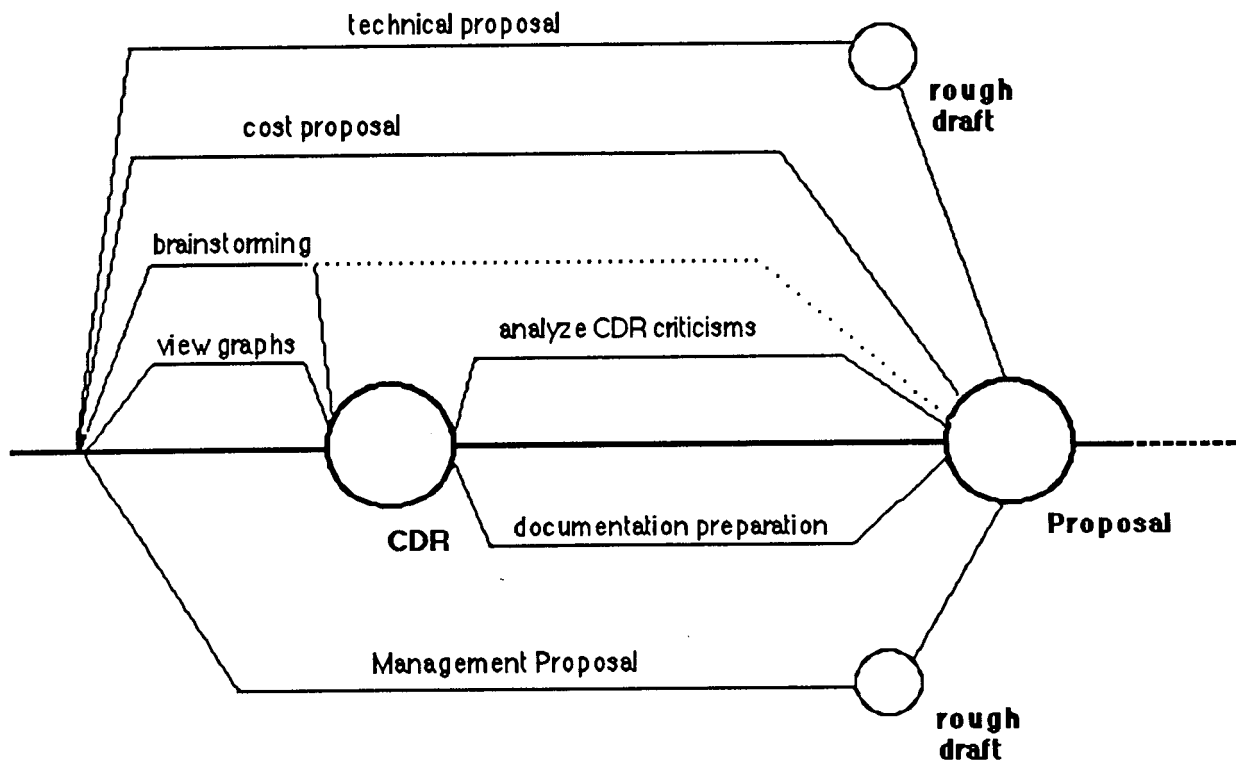


Figure 5. PERT Chart 1

4.0 Cost Proposal

Manpower Costs

Based upon the cost per hour salaries given in the class statement of work,
the cost for manpower is:

<u>JOB TITLE</u>	<u>Cost/Hour</u>	<u>Weeks</u>	<u>Hours/Week</u>	<u>Totals</u>
Project Manager	25.00	14.0	9.0	3150.00
Spacecraft Dept. Head	20.00	14.0	9.0	2520.00
Human Eng. Dept. Head	20.00	14.0	9.0	2520.00
Engineers (6)	15.00	14.0	9.0	1890.00
	X6	X6	X6	X6
Subtotal Engineers	90.0	84.0	54.0	11340.00
Manpower Cost Subtotal				21420.00
Plus 10%				2142.00
<u>MANPOWER COST TOTAL</u>				<u>23562.00</u>

Material Costs

Based upon the projected costs of previous class projects of this kind the following material costs are projected:

<u>Item</u>	<u>Per Unit Cost</u>	<u>Total Cost</u>
3 Rented Personal Computers	750.00	2250.00
Mainframe Computer Time	----	100.00
5000 Photocopies	.05	250.00
100 Transparencies	.50	50.00
100 Pages Typed	8.00	800.00
Plastic Model Parts	-----	25.00
40 Hours Consultant Fees	20.00	800.00
Material Costs Subtotal		4275.00
Plus 10%		428.00
Material Costs Total		\$4703.00

TOTAL COSTS

Using the totals from the material and manpower sections the total project costs are:

Material Cost Total	4703.00
Manpower Cost Total	23562.00
<u>TOTAL COST FOR PROJECT</u>	<u>\$28265.00</u>

Design Team Members:

Brendan O'Connor Project Manager
40 Maplewood Avenue
West Hartford, CT 06119

Brendan is currently studying for a Master's degree in Theoretical Chemistry and a Master's in Aerospace Engineering. He plans to work in the Aerospace industry in orbital mechanics or mission design.

Degrees: B.A. Chemistry June 1981
 New College
 Sarasota, Florida

Degrees Sought: M.S. Theoretical Chemistry
 M.S. Aerospace Engineering
Date Expected: June 1989

Laura E. Bass Spacecraft Design Team Leader
4011 Leeshire
Houston, Texas 77025

Laura's area of specialization is Orbital Mechanics and Advanced Programs. She is a co-operative education student at NASA/JSC, and has worked in the Payloads area and in the Advanced Programs Office. She will be working another co-op tour in the Flight Design and Dynamics Division of the Mission Operations Directorate.

Degree Sought: B.S. Aerospace Engineering
Date Expected: December 1988

Steven R. Hirshorn Human Engineering Team Leader
32 Mary Waters Ford Rd.
Bala Cynwyd, PA 19004

Steve is working on a Master's degree in Spacecraft Mission Design and Orbital Mechanics. His interests are strongly related to manned spaceflight and his career intentions are to continue working in this field with NASA as an engineer. He would also like to obtain flight status.

Degrees: B.S. Aeronautical Engineering Dec. 1986
Embry-Riddle Aeronautical University
Daytona Beach, Florida

Degrees Sought: M.S. Aerospace Engineering
Date Expected: May 1990

Daniel W. Benedict
6600 Ed Bluestein Blvd. #611
Austin, TX 78723

Dan is a member of the U.S. Air Force studying at The University of Texas under a scholarship. After completing his bachelor's degree, he will be stationed in San Antonio, Texas for Air Force Officer Training. His future plans include work in the manned spaceflight or satellite applications areas of Air Force research.

Degrees: Associate's Degree in Electronics Technology 1983
Community College of the Air Force

Degree Sought: B.S. Aerospace Engineering
Date Expected: August 1988

Alan Bowling

13519 Briar Hollow Dr.
Austin, Texas 78729

Alan is an Aerospace Engineering senior and he expects to graduate this summer. His area of specialization is Structural Dynamics. He has worked three tours as a co-operative education student at the Jet Propulsion Laboratory in Pasadena, California in the Flight Projects Support and Mission Planning sections.

Degree Sought: B.S. Aerospace Engineering
Date Expected: August 1988

David D. Chevers

16603 Neumann
Houston, TX 77058

David is interested in computer networks and their implementation in the Ada Language. He would like to work in the area of systems analysis of design for a network of computers running in a real-time or run-time environment.

Degree Sought: B.A. Computer Science
Date Expected: May 1988

James M. Treece

1302 W. 13th St.
Austin, TX 78703

Jay works as a computer programmer and consultant with the University of Texas Computation Center. He consults on the use of the University's Cray X-MP and Cyber 170/750 computers. Jay is interested in planetary science and hopes to do research in a related field.

Degrees: B.A. History May 1986
B.A. Physics May 1986
University of Texas
Austin, Texas

Degrees Sought: B.S. Aerospace Engineering
Date Expected: Summer 1988

Sung-Chu Lee

2E Delaware

Chicago, IL 60611

Sung is interested in space flight. He would like to do research in the area of remote sensing or in the field of manned space flight.

Degree Sought: B.S. Aerospace Engineering

Date Expected: August 1988

Mark Opasker

5200 North Lamar #B201

Austin, TX 78751

Mark is pursuing a career in Aerospace Engineering.

Degree Sought: B.S. Aerospace Engineering

Date Expected: May 1988